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Safety Options Report – Operating Part

(DOS-Expl)

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Introduction

1.1 The need

The Cigeo geological disposal facility for high-level and long-lived intermediate-level waste (HLW and ILW-LL) is being designed for the safe disposal of radioactive waste, with a view to precluding or limiting the burden placed on future generations, in accordance with Article L542-1 of the French Environment Code.

The type of waste for which Cigeo is being designed is final waste, which is defined under Article L542-1-1 of the French Environment Code as radioactive waste "for which no further processing is possible under current technical and economic conditions, notably by extracting their recoverable fraction or by reducing their polluting or hazardous character."

The Planning Act 2006-739 of 28 June 2006 on the sustainable management of radioactive materials and waste states that "after storage, final radioactive waste unsuitable for disposal in a surface or shallow facility due to concerns pertaining to nuclear safety shall be disposed of in a deep geological formation."

Some of the radioactive waste for which Cigeo is being designed has already been produced, while the rest will be produced through France's continuing nuclear power production and research and defence activities, and also as a result of dismantling facilities.

In Article L542-1-1 of the French Environment Code, "the disposal of radioactive waste is defined as the operation consisting in placing the substances in question in a facility specially designed for their potentially definitive disposal in compliance with the principles set out in Article L542-1. Unlike a storage facility, this implies considering the possibility of closing[1] the Cigeo facility."

For the Cigeo facility, protecting people and the environment is primarily based on the performance of safety functions during operation comparable to those performed at all nuclear facilities, and on safety standards, safety requirements and safety options adapted to the specific underground environment of the facility.

Following final closure, the repository will confine this waste within a deep geological formation to prevent dissemination of the radionuclides contained in this waste. This containment must be effective for a very long time (several hundreds of thousands of years), and must be passive, i.e. it must not require maintenance or monitoring, as specified in the ASN safety guidelines for the final disposal of radioactive waste in a deep geological formation[2], published in 2008. This will depend upon the geological environment chosen and, more particularly, on the host rock and on repository design, particularly in terms of its architecture and engineered components.

The geological disposal facility project for HLW and ILW-LL complies with Article L542-1 of the French Environment Code, which stipulates that "research into, and implementation of the required means for

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[1] During examination of the repository licence application, the safety of the facility is assessed for each different stage in its management, including final closure. A law must be passed to authorise final closure. (Article L542-10-1 of the French Environment Code).

[2] The ASN safety guidelines published in 2008 stipulate that (see 4.1, Objectives): ·

- "The fundamental safety objective assigned to the disposal of radioactive waste in a deep geological formation is the protection of human health and of the environment". This means ensuring protection against the risks linked to the dissemination of radioactive substances and toxic chemicals. "
- "After closure of the facility, the protection of human health and the environment must not depend on monitoring and institutional checks which cannot be maintained with certainty beyond a limited period. "
- "With this in mind, the geological environment must be chosen and the repository designed in such a way that, post closure, safety shall be ensured passively to protect people and the environment from the radioactive substances and toxic chemical products contained in the radioactive waste, without the need for intervention. "
- To this end, the repository design opted for must ensure that any radiological impact is kept to the lowest level that can reasonably be achieved, taking account of current scientific knowledge and technology, as well as economic and social factors".

the safe disposal of radioactive waste must be undertaken (…) with a view to precluding or limiting the burden placed on future generations.”

Passive safety following closure is a specific feature of the Cigeo project that reflects this requirement. Implementation of passive measures largely depends on the favourable properties of the Callovo-Oxfordian clay layer ("clay rock") studied for many years, mainly thanks to the Meuse/Haute-Marne[3] Underground Research Laboratory[4].

Research undertaken since 1991 on disposal in deep geological formations aims to achieve the objective of “precluding or limiting the burden placed on future generations”[5].

1.2 The Cigeo Project - a stepwise process

1.2.1 Safety iterations from the outset of the project

In 1991, the Act (1) on management of high-level, long-lived radioactive waste (HLW-LL) tasked Andra, the French National Radioactive Waste Management Agency, with assessing the possibility of disposing of waste in a deep geological formation, primarily by means of developing underground laboratories (section 2 of the Act). In 1992, ASN, the French Nuclear Safety Authority, issued a Basic Safety Rule (RFS III.2.f) setting out the long-term safety expectations with regard to the repository, the design principles, the criteria used to select suitable geological media and the terms of studies, as well as defining the fundamental objectives that must guide research on disposal.

Safety iterations were implemented as of this date, based on the acquisition of phenomenological knowledge, the development of methods appropriate to deep geological disposal, and research and development on technological solutions.

This iterative approach is thus based on the close link between design, acquired knowledge and safety assessments, as illustrated in the Figure below:

3 In application of Act No. 91-1381 of 30 December 1991, development of the Meuse/Haute-Marne Underground ResearchLaboratory in the Callovo-Oxfordian clay layer was authorised by the Government in December 1998 following the search for a site based on voluntary applications from local authorities (1992), a geological reconnaissance campaign (which began in 1993) in four preselected areas (the Gard, Haute-Marne and Meuse, and Vienne), and the assessment carried out by ASN and the CNE of three construction and operating licence applications submitted by Andra in 1996. In 2005, a transposition zone – an area in which to apply the results obtained at the Laboratory was defined. Authorisation to continue operation of the Laboratory up to the end of 2030 was granted by Decree 2011-1910 of 20 December 2011.

4 The repository licence application [for the deep geological disposal of radioactive waste] must consider a geological formation on which research has been carried out at an underground laboratory. (Article L542-10-1 of the French Environment Code).

5 Act No. 2006-739 of 28 June 2008, Article 2.

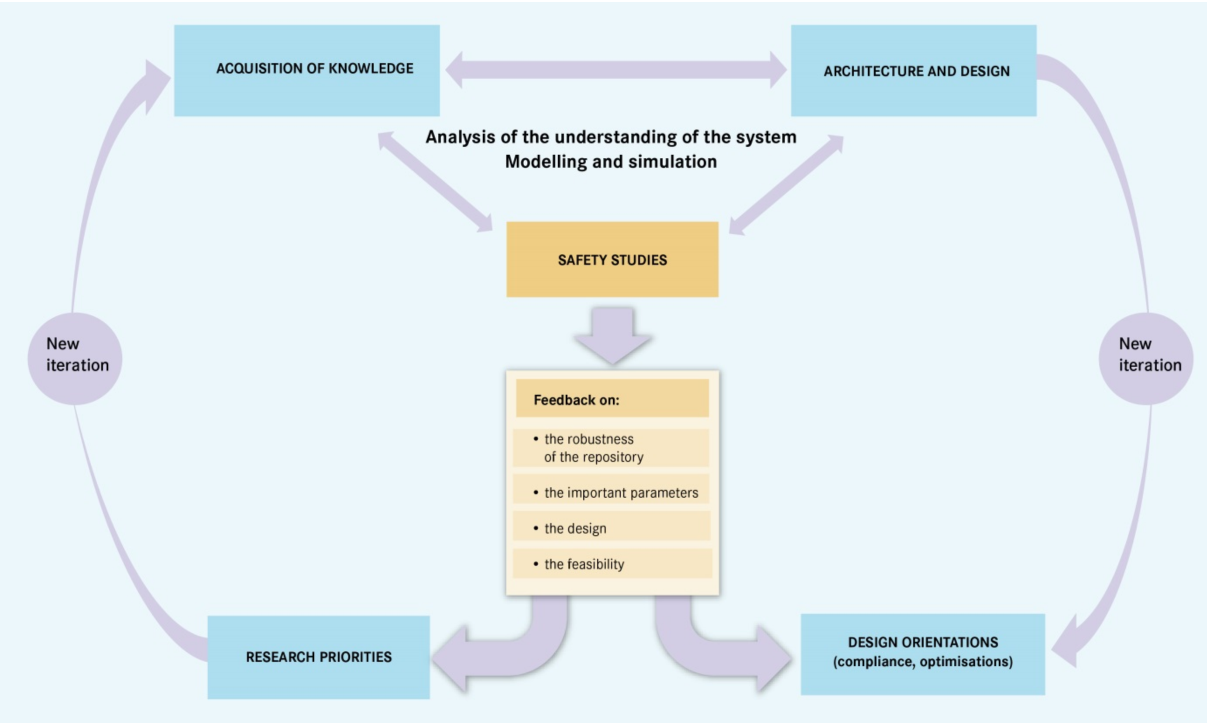

Figure 1.2-1 Diagram illustrating the iterative process

Each iteration involves knowledge acquisition and a study of the architectural designs consistent with this knowledge. With this available knowledge, models, experiments and demonstrators can be used to understand the behaviour of the concepts studied. Thanks to this approach, much has been learned through successive iterations, gradually helping to guide the choice toward solutions which demonstrate the greatest robustness in view of uncertainties in our knowledge and introducing prevention and protection measures to guard against the risks and uncertainties identified.

Each intermediate safety iteration linked to a milestone in the development of the Cigeo project has also been examined by ASN and subject to peer review, as a result of which it has been possible to identify safety issues, with a view to licensing, and propose safety options, the subject of this document, which also incorporates this feedback.

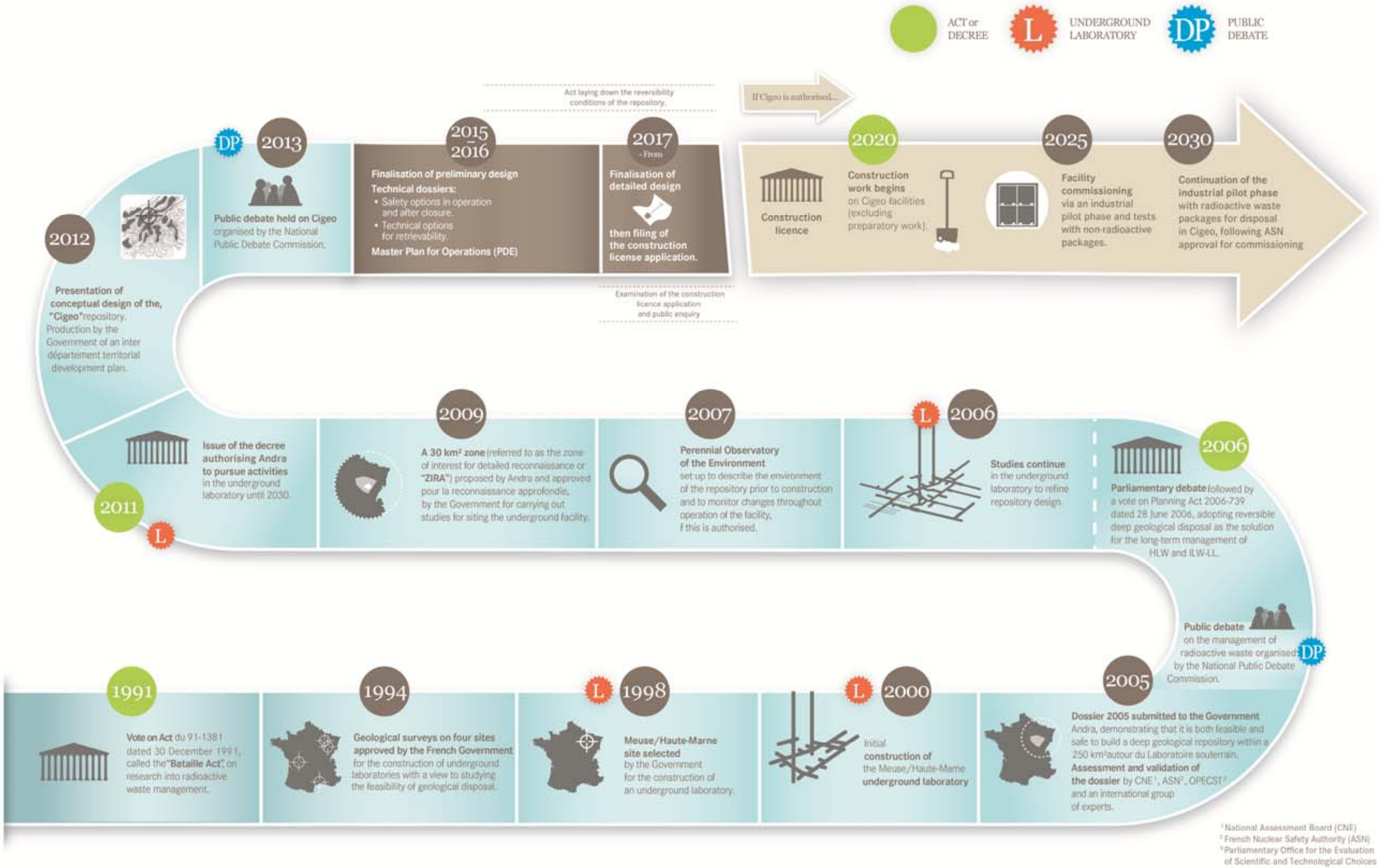

Figure 1.2-2 Cigeo project development, an iterative process integrating safety stage-by-stage since 1991 - key milestones

1.2.2 Key milestones

Since 1991, Andra has undertaken a substantial research programme on disposal in a clay (clay rock) layer formed around 155 million years ago, the Callovo-Oxfordian formation, located at a depth of between 400 and 600 m.

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

In 2005, **after 15 years of research** completed in accordance with the Act of 30 December 1991, Andra produced Dossier 2005 (2) on the feasibility of building a reversible repository for high- and intermediate-level, long-lived waste in the Callovo-Oxfordian clay rock formation studied at the Meuse/Haute-Marne Underground Research Laboratory. At the time of producing Dossier 2005, the aim of the feasibility study was to demonstrate the existence of technical solutions for building a safe, reversible repository, rather than making a definitive decision on the subject; the solutions proposed in Dossier 2005 were not set out as optimal solutions, particularly insofar as regards operating safety and radiation protection. The repository would be located within the 250 km^2 area surrounding the Underground Research Laboratory recognised as having similar characteristics, whilst ensuring that the results of the safety analysis for this area would apply. **In Dossier 2005, a distinction is made between two phases in the life cycle of the repository, leading to two additional safety analyses: one regarding the operating phase and the second regarding post-closure evolution related to the specific characteristics of the repository**. The Dossier then went through a scientific and technical evaluation process, addressed in the general report of the CNE, the National Assessment Board set up under the Act of 1991, an ASN Opinion, and the report of the international expert review conducted under the aegis of the OECD Nuclear Energy Agency at the request of Andra's supervisory ministries. These assessments confirmed Andra's results on the feasibility and safety of building a deep geological disposal facility at the site studied in Meuse/Haute-Marne[6].

On 28 June 2006, following the review of Dossier 2005 and the public debate held at the beginning of 2006, Planning Act 2006-739 on the sustainable management of radioactive waste was adopted (3). This Act stipulates that after storage, final radioactive waste which, for reasons of nuclear safety and radiation protection, cannot be disposed of in a surface or near-surface facility shall be disposed of in a deep geological formation. The Planning Act of 28 June 2006 tasks Andra with designing and building a reversible disposal facility for this type of waste.

In 2008, in a similar vein to that of 1991, ASN updated Basic Safety Rule No. III.2f, thereby replacing it with the Safety guidelines for the final disposal of radioactive waste in a deep geological formation. In particular, the updated version takes into consideration the studies carried out by Andra and the review, as well as guidelines that had by then been defined in the Planning Act of 28 June 2006. The main changes incorporated in the draft update to the BSR relate to the concept of reversibility, the control of nuclear materials, the objectives of facility monitoring and the definition of repository safety functions.

In 2009, to study the siting of the underground facility, Andra proposed to the French Government a 30 km² underground zone (ZIRA, or zone of interest for detailed reconnaissance) located within the 250 km² area defined in 2005 and for which the results from the URL can be applied. **In 2009, in line with an iterative approach to repository design, closely linking design, scientific knowledge and safety, Andra presented an interim report entitled "Dossier 2009"** which it submitted to ASN as per Decree 2008-357 of 16 April 2008 which implements Article L.542-1-2 of the French Environment Code

[6] Extract from the ASN Opinion published in 2006: “The Dossier 2005 Argile report submitted by Andra to its supervising ministers in June 2005 has been reviewed by IRSN and was the subject of an opinion delivered by the expert advisory committee on radioactive waste management during its session of 12-13 December 2005. These reviews reveal that key results related to the feasibility and safety of a geological repository have been obtained at the Bure site. It is the view of the ASN that deep geological disposal is the only disposal solution possible. "

and stipulates the requirements relating to the French National Radioactive Materials and Waste Management Plan. In 2010, ASN published an opinion on each of these dossiers.

In 2010, the zone proposed by Andra, located a few kilometres from the Underground Research Laboratory, was approved by the government, following an opinion issued by ASN, the CNE (National Assessment Board) and following consultation with elected officials and the Local Information and Oversight Committee (CLIS) for the laboratory. Andra subsequently undertook a new geological reconnaissance campaign, the results of which confirmed that the clay layer in the zone exhibits characteristics favourable to the siting of a deep geological disposal facility. In the event that a licence for Cigeo is issued, the underground facility will be built in this zone.

In 2011, Andra began work on the industrial design phase of the Cigeo project. This phase is divided into several key stages including conceptual design, and more detailed basic engineering design; the results of studies related to the detailed engineering design will be used to support the future licence application. The guidelines followed regarding the conceptual design for the industrial project were set out in a project owner's report used during the 2013 public debate on the Cigeo project.

From 15 May to 31 July 2013 and from 1 September to 15 December 2013, a public debate on the Cigeo project was organised by the French National Public Debate Commission (CNDP). Andra, as Cigeo Project Owner, presented the provisional inventory of waste to be disposed of, the proposed sites for the Cigeo facilities, a set of Andra proposals regarding reversibility, and the results of the conceptual design phase.

Between 2009 and 2014, Andra published a series of interim dossiers which have been assessed by IRSN, the technical support organisation acting under the aegis of ASN. As part of each such assessment, ASN issued an Opinion in which it states its position and sets out requirements regarding the safety options report and the licence application. All this information is available on the ASN website.

On 5 May 2014, following the public debate on the Cigeo project, and submission of the conclusions from this debate, Andra's Governing Board decided (4) that Andra would submit before the Government a series of documents including a proposal for a master plan relative to the operating of Cigeo, the Safety Options Report and the Retrievability Technical Options Report with a view to examination of the Cigeo construction licence application. "

In a letter dated 19 December 2014 (ref. CODEP-DRC-2014-039834) ASN set out its expectations with regard to the safety options for Cigeo. In particular, it mentions that the Safety Options Report "must clearly explain the objectives, concepts and principles used to guarantee the safety of the facility during operation [...]. These questions must be accompanied [...] by a detailed list of the information needed for the safety options file to be properly examined."

At the stage of completing the basic engineering design (APS), Andra produced a file containing the following documents:

- documents relating to safety options for the facility during the operating and post-closure phases:
  - ✓ the Safety Options Report relative to Operating (DOS-EXPL), i.e. this document, the purpose and content of which are described in the sections below;
  - ✓ the Safety Options Report relative to Post-closure (DOS-AF), which sets out the post-closure safety objectives, principles and functions, the options selected and their related performance, management of uncertainty and initial long-term impact assessments (5);
- the first draft of the preliminary specifications for acceptance of primary packages at Cigeo, i.e. the preliminary specifications of the specifications required for the licence application (6);

- documents relative to provisions for ensuring reversibility:
  - ✓ the proposed Master Plan for Operations at Cigeo (PDE), which presents the reference progression of the Cigeo project, including the industrial pilot phase and the possibilities of reversibility in terms of project management (7);
  - ✓ the Retrievability Technical Options Report (DORec), which presents the main technical options which will allow waste packages to be retrieved (8);
  - ✓ the document relative to the study on Cigeo's adaptability for the possible disposal of fuel and related technical components (9);
  - ✓ the document relative to Cigeo's adaptability for managing waste volume reserves and related technical components (10).
- draft notice limited to a presentation of the operator's technical capabilities (11).

Together, the documents listed above constitute a design study for the Cigeo disposal facility at the time of completing the basic engineering design (APS), and factor in the specific nature of the facility in terms of its construction in incremental stages and the different phases in its life cycle, especially with regard to the post-closure phase.

1.3 The scope and purpose of this document

1.3.1 The scope of the project

The Cigeo project complies with Article L542-1 of the French Environment Code, which stipulates that "research into and implementation of the required means for the safe disposal of radioactive waste must be undertaken (…) with a view to precluding or limiting the burden placed on future generations".

In Article L542-1-1 of the French Environment Code, the disposal of radioactive waste is defined as "the operation consisting in placing the substances in question in a facility specially designed for their potentially definitive disposal in compliance with the principles set out in Article L542-1". Hence, unlike a storage facility, these objectives imply a need to "close" the facility.

Furthermore, the same article states that the disposal of radioactive waste in deep geological formations is the disposal of these substances in an underground facility specially designed for this purpose, in compliance with the principle of reversibility. In accordance with Article L542-10-1 of the French Environment Code, the conditions required to ensure reversibility are stipulated in legislation passed after the licence application is submitted.

The Cigeo disposal facility is a basic nuclear installation designed for the management of final waste[7] with radioactivity levels and half-lives that preclude its safe, long-term disposal in surface or near-surface disposal facilities.

Cigeo is made up of:

- an underground facility (shafts and access ramps, drifts and disposal cells);
- surface facilities (facilities located immediately above the underground repository at the top of the shafts, and facilities built to the south of the disposal facilities, at the ramp heads).

[7] Final waste is defined under Article L542-1-1 of the French Environment Code as radioactive waste "for which no further treatment is possible under existing technical and economic conditions. Treatment particularly entails extracting any part of the waste that can be recycled or reducing any pollutant or hazardous substances it contains".

Compared to other types of basic nuclear installation, Cigeo has the following distinctive characteristics:

- underground parts located several hundred metres below ground, of limited diameter and some over a kilometre in length, requiring certain standards applicable to conventional basic nuclear installations to be adapted to these specific characteristics (see Chapter 3 of the present Volume);
- the facility is expected to operate for around a hundred years, including an industrial pilot phase planned at the start of operating and prior to routine operating, together with the development of the facility in successive phases thereby enabling improvements as and when they are identified and for which studies are still required with a view to proposing solutions that are feasible in industrial terms and the safety of which can be demonstrated;
- a fundamental objective to protect human life and the environment in the long term after closure[8], based on 'passive' safety without requiring intervention and to be taken into account in the design of the facility as well as during its construction and operating. This implies a safety strategy aimed at implementing safety analysis during operating and post-closure in parallel and in a coordinated manner (see Chapter 3).

1.3.2 Purpose

The Safety Options Report – Operating Part [DOS-Expl] presents the functions performed by the Cigeo repository during the operating phase, the main technical options and safety options planned to prevent the various internal and external risks and a preliminary estimate of the impact on human health and the environment during normal operating as well as in the event of incident or accident situations.

To achieve these objectives, the Safety Options Report – Operating Part contains four volumes, essentially covering the following points:

- in Volume I:
  - ✓ the safety principles, approach and management applied at Cigeo, mainly including the safety functions and the relevant regulatory texts;
- in Volume II:
  - ✓ input data relative to the waste packages used as the basis for facility design and operating;
  - ✓ the key characteristics of the site, demonstrating its suitability for the location of the facilities and used as the basis for designing the facilities;
  - ✓ the main technical options relating to the structures and equipment to ensure that Cigeo is operational;
  - ✓ the main options chosen in relation to operating, mainly including management of waste packages, organisational and human factors and effluents;
- in Volume III:
  - ✓ a summary description of how waste packages will be transported from their arrival at the facility to their emplacement in the disposal cells;
  - ✓ the inventory of internal and external risks, in application of the principle of defence in depth and related to the technical options selected and the bounding scenarios used for facility design;
  - ✓ a preliminary estimate of the impact on human health and the environment for each bounding scenario used;
- in Volume IV:
  - ✓ a presentation of the options and operations envisaged for the closure of Cigeo, together with a preliminary inventory of the related risks.

[8] It should be mentioned that the Act of 28 June 2006 states that a law must be passed to authorise final closure of Cigeo. According to current plans, final closure of Cigeo is expected in around 2150.

Given that the repository is expected to operate for around a hundred years, and that it will be developed in stages throughout that period, certain technical solutions which, at this stage, seem to offer potential improvements are included in Volume II. Depending on how much progress has been made on the demonstration and the results of studies planned during the basic engineering design phase, certain technical solutions may be incorporated in the report submitted in support of the licence application or, if necessary, following issue of the licence and according to stages that will be specified in the licence application.

2

General presentation of the Cigeo project

2.1 What type of waste will be disposed of at Cigeo?

The Planning Act of 28 June 2006 on the sustainable management of radioactive materials and waste states that: "after storage, final radioactive waste that cannot be disposed of at surface or near-surface facilities for reasons of safety or radiation protection is disposed of in a deep geological formation". This Act entrusts Andra with the responsibility for designing, building and managing (...) radioactive waste disposal facilities.

The design and safety options, presented in this document, apply to the disposal of high-level waste (HLW) and intermediate-level long-lived waste (ILW-LL) with radioactivity levels and half-lives that preclude its safe, long-term disposal in surface facilities or in the near-surface disposal facility also being studied by Andra.

HLW and ILW-LL waste is primarily generated by the nuclear power industry and related research, as well as, to a lesser extent, defence-related activities.

The Cigeo project has therefore been designed to receive approximately 10,000 m^3 of HLW and 75,000 m^3 of ILW-LL. Currently, around 60% of the long-lived intermediate-level waste (ILW-LL) and 30% of the high-level waste (HLW) has already been generated.

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

Given that it is planned that Cigeo will operate for over a hundred years, the repository is designed in successive phases to be flexible enough to adapt to possible changes in France's energy policy and the consequences of such changes on the nature and volumes of the waste subsequently generated. Studies on Cigeo's adaptability to the disposal of waste other than that mentioned above, mainly meaning spent fuel, are dealt with in specific documents (see Section 1, this Chapter).

2.1.1 High-level waste (HLW)

HLW has a level of radioactivity ranging between several billion and several tens of billions of Becquerel per gram and it generates heat. Some of the radionuclides it contains have very long half-lives. A distinction is made between moderately exothermic waste, called HLW0, and waste which has much higher thermal output (called HLW1 and HLW2).

This waste is mostly vitrified waste from spent fuel reprocessing. It includes fission products and minor actinides formed by nuclear reaction within the fuel during use inside a reactor. It has been processed to separate it from uranium and plutonium, i.e. radioactive materials which can be recovered. It is then calcined and incorporated into a glass matrix. The glass produced is hot cast into a stainless steel container.

Other waste packages, in very limited quantities, are considered as HLW packages. This primarily includes packages of 'technological waste' produced during operations at the La Hague vitrification facility and certain used sealed sources from the CEA.

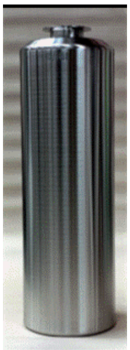

Figure 2.1-1 Image of a HLW vitrified waste package

2.1.2 Intermediate-level long-lived waste (ILW-LL)

ILW-LL waste is mainly made up of structural elements of spent fuel assemblies and waste related to operating, maintenance and dismantling of nuclear facilities. When generated, this radioactive waste can be in liquid or solid form. In order enable handling, storage, transport and/or disposal, it is conditioned in waste packages. For around the last twenty years, this waste has systematically been conditioned as and when it has been produced. Before this, waste was stored in raw form pending development of a suitable conditioning process. This type of waste, known as "legacy" waste, must undergo waste recovery and conditioning operations before it can be placed in packages. Some of these operations are already in progress.

Three methods are widely used to produce waste packages:

- some solid waste is placed directly in containers and immobilised using a cementitious material poured into the containers. This process, known as encapsulation, is widely used for solid waste, particularly for metal waste produced during nuclear facility operating or dismantling;
- other waste (e.g. fuel cladding and tubes) has a geometric form which makes it possible to compact it using a press and thus significantly reduce its volume. The compacted blocks are then placed in containers;
- liquid waste must be treated and then mixed with a material to solidify it before it is placed in containers. In the past, the material most widely used to condition this waste from various sites was bitumen. It is now increasingly being replaced by cement or glass, and research into alternative conditioning processes is also being carried out. Vitrification, in particular, is used to condition effluents produced when rinsing facilities before dismantling.

Containers of different sizes are used for conditioning ILW-LL and they may be made of non-alloy steel, stainless steel, reinforced or fibrous concrete.

Figure 2.1-2 Illustration of an ILW-LL vitrified waste package

2.2 The Cigeo disposal facility

The Act of 28 June 2006 defines the disposal of radioactive waste as the operation consisting in placing the substances in question in a facility specially designed for their potentially definitive disposal. The European Directive of 19 July 2011 defines disposal as “the emplacement of spent fuel or radioactive waste in a facility without the intention of future retrieval”. This is in line with the definition of final disposal given by the International Atomic Energy Agency (IAEA), namely "the emplacement of radioactive waste into a facility or a location with no intention of retrieving the waste".

The facilities at Cigeo form a single basic nuclear installation, and include (see Figure below):

- surface facilities divided into two distinct sets:
  - ✓ the "ramp zone" designed for receiving primary packages of HLW and ILW-LL and preparing them for disposal, with a surface area of approximately 200 hectares;
  - ✓ the "shaft zone" designed for underground construction support activities, with a surface area of approximately 250 hectares;
- an underground facility consisting of surface-bottom connections (ramps and shafts), package disposal sections and logistics support zones.

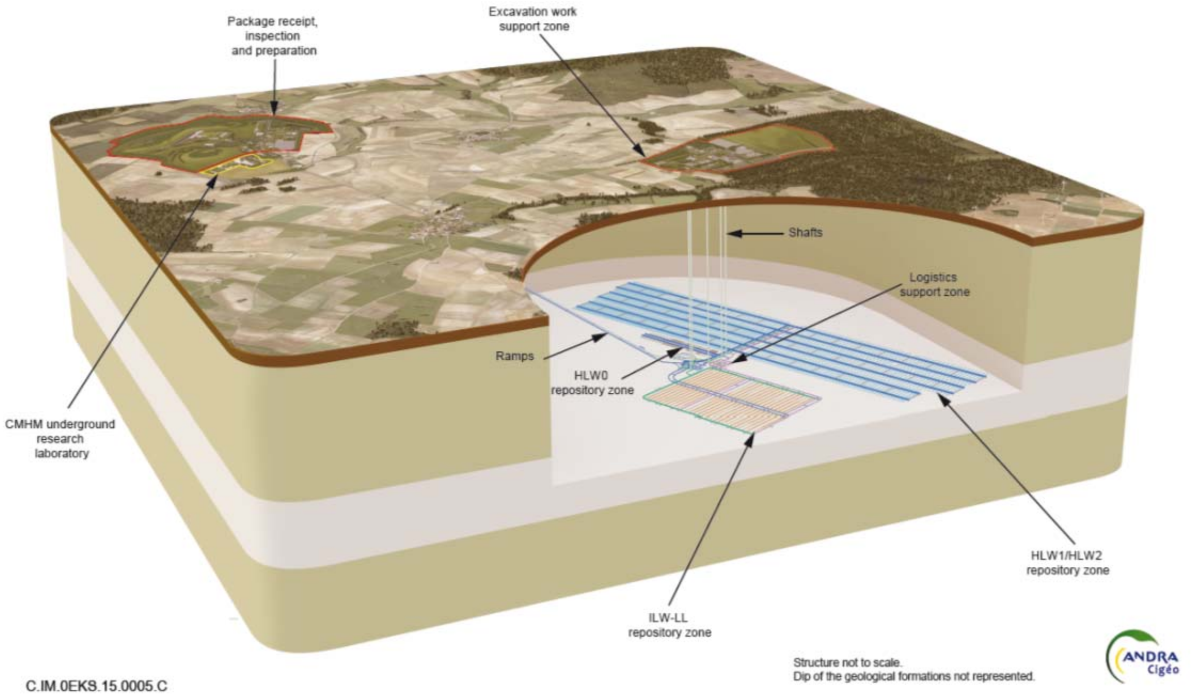

Figure 2.2-1 Diagram showing the surface and underground facilities at Cigeo

2.2.1 Surface facilities

The nuclear facilities in the ramp zone include all the surface buildings designed for receiving and unloading transport containers containing primary radioactive waste packages, for conditioning primary packages in disposal packages, carrying out related inspections, and placing packages in casks for transfer into the underground facility. They also include facility operating support units (maintenance workshops, stores, equipment and changing rooms, etc.).

Waste packages will be delivered to the disposal facility in transport containers. The facility includes buildings where the vehicles used to transport these containers are received and inspected.

After unloading the containers in the receiving areas, primary packages are removed from the transport containers in an unloading building. The facilities for receiving and unloading packages may also be used to return waste packages to producer sites. Waste packages are then transferred to the conditioning building where they are placed in disposal packages in two stages: primary packages are placed in a container and then the container is closed with a lid sealed to the body of the container.

The primary package and its container together form a "disposal package" (CS).

Once assembled, the disposal package is placed inside a "cask" and transferred to a ramp to be lowered into the underground facility for disposal.

The buildings in which these operations are carried out are partially-underground monobloc reinforced concrete structures (see Figure 2.2-2). Inspections are carried out at all stages of the operations.

The stepwise development of the Cigeo repository implies a two-stage deployment of the unloading, conditioning and inspection structures within the ramp zone (see Volume II):

- first, a nuclear facility called "EP1", for ILW-LL packages and the first HLW0 packages received will operate at the site from 2029 to 2100;
- second, a nuclear facility called "EP2", for HLW1/HLW2 packages, built in the second stage and operating from 2079 to 2145.

The ramp head is a key structure which will be in use throughout the entire operating phase of the disposal facility.

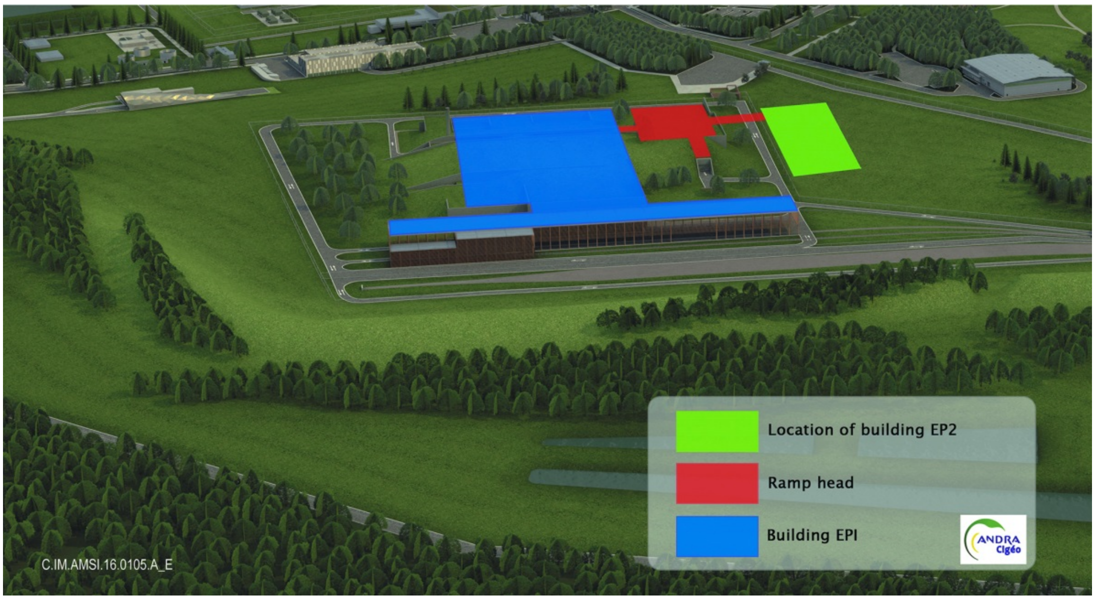

Figure 2.2-2 Diagram showing the geographical perimeters of buildings located in the ramp zone

Surface facilities in the shaft zone mainly include the equipment and buildings related a) to underground nuclear operations, and b) to construction and extension works on the underground structures. Support and maintenance equipment for nuclear operations in the underground facility will be located to the south of the shaft zone. In addition to structures housing machinery required for handling and transfer via a dedicated shaft, this zone contains structures dedicated to access and transfer of operating personnel to the bottom, as well as separate ventilation units to supply fresh air and extract foul air respectively (see Volume II).

The buildings related to extension work on the underground facility are located in the centre and to the north of the shaft zone. These are buildings related to the shafts which connect the surface to the "construction" section of the underground facility for the transfer of "construction" personnel, the supply of fresh air and extraction of foul air, and the supply and removal of construction equipment and materials. Located nearby are the construction work support facilities, including concrete mixing plants, storage for construction equipment and materials (including concrete segments) and related maintenance workshops and stores. Spoil piles are located north of this zone.

Figure 2.2-3 Diagram showing the geographical perimeters of the shaft zone

2.2.2 Surface-bottom connections

The ramps

The ramps are two parallel sloping tunnels, built using a tunnel boring machine. Tunnel liner design is adapted to the different geological layers passed through. The ramps are connected at the top to the "ramp head" building and at the bottom to the "Operating" logistics support zone:

- the "Package" ramp will be used to transfer disposal packages to the underground facility via an inclined transfer system enabling disposal packages to be lowered and, if necessary, raised back up;
- the service ramp is used for evacuation and emergency operations, maintenance and, when closure operations are authorised, the transfer of materials to build the closure structures.

The shafts

There will be five shafts connecting the shaft zone surface facilities to the underground facility. Shaft liner design is adapted to the different geological layers passed through.

Two shafts are dedicated to underground operations:

- the "Operating Personnel Fresh Air Ventilation" shaft to transfer personnel from the surface facilities to the operating logistics support zone and to supply fresh air to the underground facility from the ventilation units at the surface;
- the "Operating Foul Air" shaft to extract foul air from the underground structures in the operating zone.

Three shafts are for underground construction work:

- the "Construction Personnel Fresh Air" shaft to transfer personnel from the conventional surface facilities to the “Construction” logistics support zone, and to supply fresh air to the construction zone;
- the "Construction Foul Air Ventilation" shaft to extract foul air from the drifts during construction work;
- the "Construction Equipment & Materials" shaft to transfer equipment and materials required for construction work and to remove muck from excavation to the surface. This shaft is also used to transfer very large equipment.

<u>Long-term maintenance and closure of surface-bottom connections</u>

Constructive measures will be implemented to ensure the maintenance of these connections throughout the operating phase of Cigeo.

Surface-bottom connections will undergo closure operations when final closure of the Cigeo facility is authorised. These operations include sealing and backfilling and are described in Volume IV of this Report.

2.2.3 **The underground facility**

The underground facility architecture is designed in such a way as to ensure that nuclear operating activities are physically separated from other activities, in particular from works to extend the repository zones.

This also meets post-closure safety requirements which, in particular, require that ILW-LL, HLW0 and HLW1/HLW2 be emplaced in separate sections.

The underground facility is constructed in the Callovo-Oxfordian clay rock layer and it is designed to ensure a maximum thickness of undisturbed clay rock on each side of the disposal cells.

The underground facility is made up of the following three major functional blocks:

- the "Construction" logistics support zone (ZSL-T) located directly above the Construction shafts;
- the "Operating" logistics support zone (ZSL-E) located directly above the Operating shafts;
- the repository zone in which the ILW-LL waste disposal sections and HLW0 and HLW1/HLW2 waste disposal sections are located.

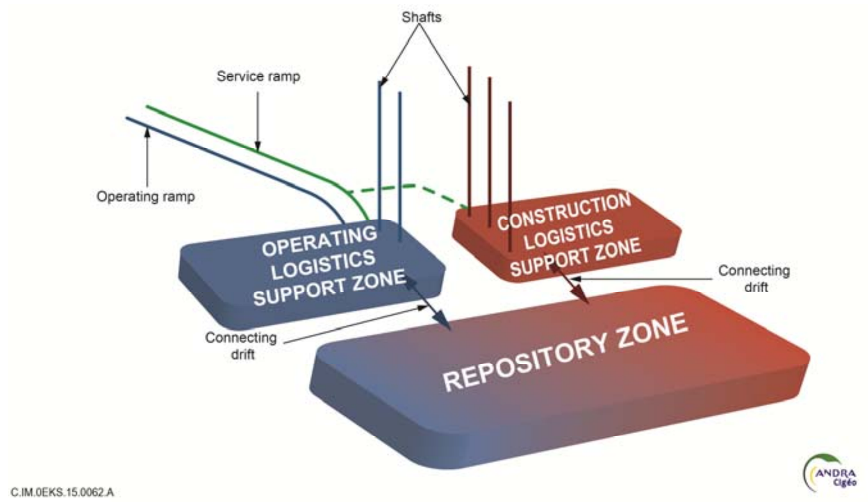

Figure 2.2-4 Image showing the different zones and surface-bottom connections

A detailed description of Cigeo (component parts, equipment and operations) and, more particularly, the design options and technical solutions being considered, is given in Volume II, Chapter 2 of this Report.

2.3 Location of the Cigeo facility

The future "Cigeo" geological repository will be located in eastern France, at the border between the Meuse and Haute-Marne departments. Research has been carried out in this area since the 1990s, leading to the identification of a zone within the Paris basin whose geological characteristics make it suitable for the deep geological disposal of high- and intermediate-level long-lived radioactive waste, as well as a smaller zone with surface area of approximately 250 km^2 within which the characteristics of the host layer are very similar to those observed in the Underground Research Laboratory (12).

The choice of a site for the Cigeo facilities (surface and underground facilities) is the result of a stepwise approach implemented since 2006, and including a major step in 2009. In 2009, Andra submitted a Proposal of a 30 km^2 zone of interest for detailed reconnaissance (ZIRA) and surface siting scenarios (13). At the request of ASN, this document was examined by IRSN.

On 5 January 2010, ASN submitted an Opinion[9] relative to Andra's document to the French Minister of State, the Minister of Ecology, Energy, Sustainable Development and the Sea, and the Minister of Higher Education and Research. In its Opinion, ASN stated that the criteria used by Andra to select the zone of interest for detailed reconnaissance (ZIRA) were relevant and consistent with the ASN Safety guidelines for the final disposal of radioactive waste in a deep geological formation, published in 2008. ASN stated that the location proposed by Andra for the ZIRA was satisfactory from the point of view of safety and that it had no objections to Andra's proposal to carry reconnaissance studies in this zone (14).

[9] ASN Opinion No.2010-AV-0084 of 5 January 2010 on Andra's Proposal of a Zone of interest for detailed reconnaissance (ZIRA) and surface siting scenarios for a reversible disposal facility in a deep geological formation

Andra's proposal was primarily based on the following sources:

- the results of geological investigations, especially those conducted in 2007 and 2008, which provided a uniform level of geological knowledge on the scale of the transposition zone, and analysis of geological and safety-related criteria to be considered in deciding on the location of the underground facility;
- analysis of environmental and safety-related requirements to be considered for siting surface facilities;
- discussions with local stakeholders, which have helped identify the local planning and integration criteria to be considered in deciding on the location of the disposal facility project.

The reconnaissance studies carried out in the transposition zone in 2007 and 2008 were primarily aimed at developing thorough knowledge of the entire sector in question. With this in mind, fourteen boreholes and a 2D seismic campaign covering a total length of 170 kilometres were carried out, and former seismic campaigns covering 130 kilometres were reprocessed. The results confirmed the perimeters of the transposition zone, as defined in Dossier 2005[10], in particular confirming the uniform nature of the sedimentary environment and the properties of the layer, as well as the absence of minor faults.

Based on these studies and the geological models derived from them, Andra was able to define a zone of interest for detailed reconnaissance (ZIRA) factoring in the following criteria:

- the ZIRA should preferably be sited in the zone identified as most suitable with regard to geological and safety criteria;
- the ZIRA should be of a large enough surface area for the underground facility to be located within it;
- it should include a potential site for the ramp access;
- it should include a potential site for the main access shafts;
- it should avoid siting any facilities in built-up areas of villages.

In studies carried out from 2007 to 2009, the possibility of separating part of the surface facilities from the underground facility by means of a ramp was also examined in a bid to provide flexibility as to the location of the ramp entrance of up to around 5 kilometres from the shaft zone (based on a gradient of 10%). Two surface zones, possibly separated, were thus considered: the "shaft" zone, which must be located immediately above the underground facility, and the "ramp" zone.

Based on all these criteria, a zone in which to construct the underground facility with site coverage of approximately thirty square kilometres was defined. The repository structures within the ZIRA will be located at a depth of 525 metres and the thickness of the Callovo-Oxfordian layer at the centre of the ZIRA is 148 metres. Half the surface area of the ZIRA is located in a wooded area, the other half being situated in grassland or farmland. The ZIRA is situated in the two "communautés de communes" (intercommunal authorities) of Haute-Saulx and Val d'Ornois.

[10] In Dossier 2005, Andra defined the contours of a zone called the transposition zone, in which the containment properties of the Callovo-Oxfordian layer and the disturbances caused by a repository would be considered equivalent to those determined in the Meuse/Haute-Marne Underground Research Laboratory. The outline of this zone is therefore based on geometric criteria (thickness and depth of the layer) and also on a set of sedimentological, stratigraphical and structural data resulting in the proposal of this zone, with a surface area of 250 square kilometres, within which the properties of the layer were shown to be continuous and uniform. The primary purpose of the criteria used to define the transposition zone, selected in 2005 and subsequently confirmed, is to ensure the quality of the Callovo-Oxfordian formation's containment capabilities. They are therefore based on: the thickness of the layer, the structural framework, clay rock mineralogy and the geomechanical behaviour of the rock.

The Zones where surface facilities will be located have been identified by Andra in light of the following environmental restrictions: flood zones, built-up areas and protected natural areas. The following safety-related constraints were also analysed: means of access, the industrial environment and flyover zones, etc.

As shown in Figure 2.3-1, the "ramp zone" is located within a zone which crosses two departments, in Saudron on the Haute-Marne side and adjacent to the Meuse department. This zone encompasses the Underground Research Laboratory. The "shaft zone" is located in the centre of the ZIRA in Bure, in the Ormançon Valley forest, with emphasis being placed on siting in a wooded area to limit the amount of farm land taken.

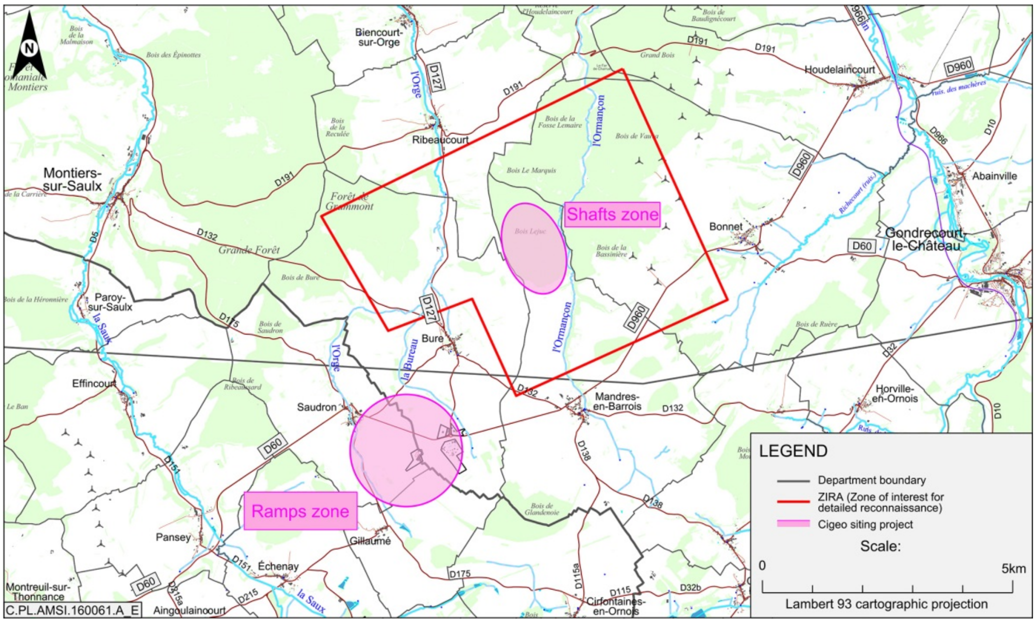

Figure 2.3-1 *Location of the ZIRA and the zones where surface facilities may be located*

2.4 Stepwise development of Cigeo

2.4.1.1 Successive phases

Development of the Cigeo project is divided into the following successive phases:

- ***initial design*** of the facility (conceptual design, basic engineering design, detailed engineering design, project design and construction design) (15), i.e. the phase during which the technical specifications for facility structures, buildings and procedures are defined. This is the current project phase. The design of Cigeo is regularly assessed (by ASN, the CNE [National Assessment Board] and industrial reviews). It includes the construction licence application; During the initial design phase, the first work on the site, mainly including diagnostics (preventive archaeology, geotechnical studies, reconnaissance, preparatory works, off-site support facilities) may be performed;
- ***initial construction*** of Cigeo, during which the first part (or “phase[11]"), of the facility is built. Provided that the licence for Cigeo is granted, this includes construction of surface buildings associated with operating the surface nuclear facility, surface-bottom connections and underground structures designed to receive the first waste packages; During the initial construction phase (and depending on the construction schedule), studies are carried out on component and equipment construction design, up to their actual construction;

[11] Each intermediate "phase" implies a 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.

- ***the operating phase*** which will be implemented for around a hundred years and during which package reception and emplacement will be carried out in parallel to underground facility extension work, in successive phases, so that all the inventory packages can be accepted. Operating will only begin once ASN grants the operating licence (reception of the first radioactive waste packages used for active tests). Operating also includes, subject to authorisation, partial closure works (closing off disposal cells and zones). In addition, construction, modification and renovation works on surface buildings will be undertaken. During the Cigeo operating phase, studies will continue with a view to improving the design, and especially on optimising each successive phase;
- subject to authorisation by the passing of legislation, final closure and the dismantling of surface facilities. Cigeo will then enter its ***monitoring phase.***

The provisional milestones for the licensing and implementation of Cigeo are described in more detail in the proposed Master Plan for Operations (PDE) (7).

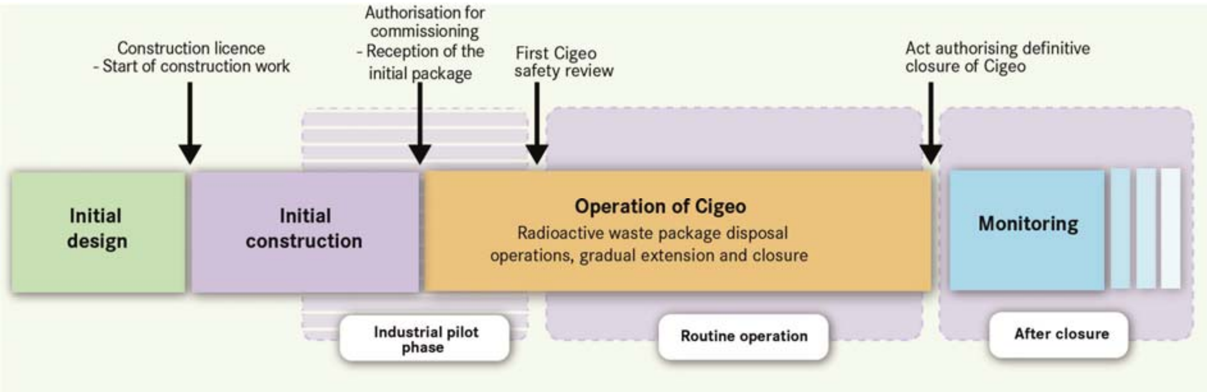

Figure 2.4-1 Diagram showing the main phases in the Cigeo project

2.4.1.2 Open-ended design and stepwise development

During the hundred years in which Cigeo will operate, the facilities will be developed gradually, by means of successive construction phases. By agreement, the first phase in the construction works is known as (T1[12]), with later phases (TU) and so on until completion of the disposal facility. Until such time as the last phase of the underground structures has been completed, part of the underground facility will be for nuclear operations and part will be "under construction", i.e. the part where works to construct new cells will be conducted.

The fact that Cigeo will operate for around a hundred years implies that the facilities need to be flexible and adaptable so that they can be adapted to any future developments, and benefit from feedback on the first few phases and from scientific and technical advances that may come about given the timescale of several decades. The safety options described in this Report are those which are planned at this stage in the design and on which the licence application will be based. In the course of time and with improvements to techniques, they may change, subject to authorisation by ASN. The main technical developments which Andra has identified at this stage are the direct disposal of ILW-LL packages without being placed in containers, increasing the length of HLW1/HLW2 cells, and increasing the diameter of cells used for the disposal of ILW-LL packages.

Given the very individual nature of the Cigeo project, Andra's Governing Board, at its meeting on 5 May 2015, announced that an industrial pilot phase would be included at the start of operating and prior to routine operating in order to confirm - under real conditions and in addition to the tests conducted in the Underground Research Laboratory - the facility's design options. A review of this industrial pilot phase will be drawn up by Andra and presented to Parliament and the assessment bodies. With regard to safety, the objectives of the industrial pilot phase announced by Andra in the PDE (7) include risk management under operating conditions and the possibility of monitoring the repository structures.

[12] In what follows, the terms "Phase 1", "T1 phase", etc. may be used without distinction.

According to the reference progression of the Cigeo project described in the proposed Master Plan for Operations (PDE), the first series of operations to close cells and drifts in the HLW0 section will begin in around 2070 and the first series of operations to close cells and drifts in the ILW-LL section will begin once the section is full, in around 2100. Cells and drifts in the HLW1/HLW2 section are expected to be closed in around 2145, prior to final closure of Cigeo if authorised by legislation.

The industrial pilot phase, combined with post-closure safety functions, will thus help demonstrate the ability to seal the disposal cells and drifts.

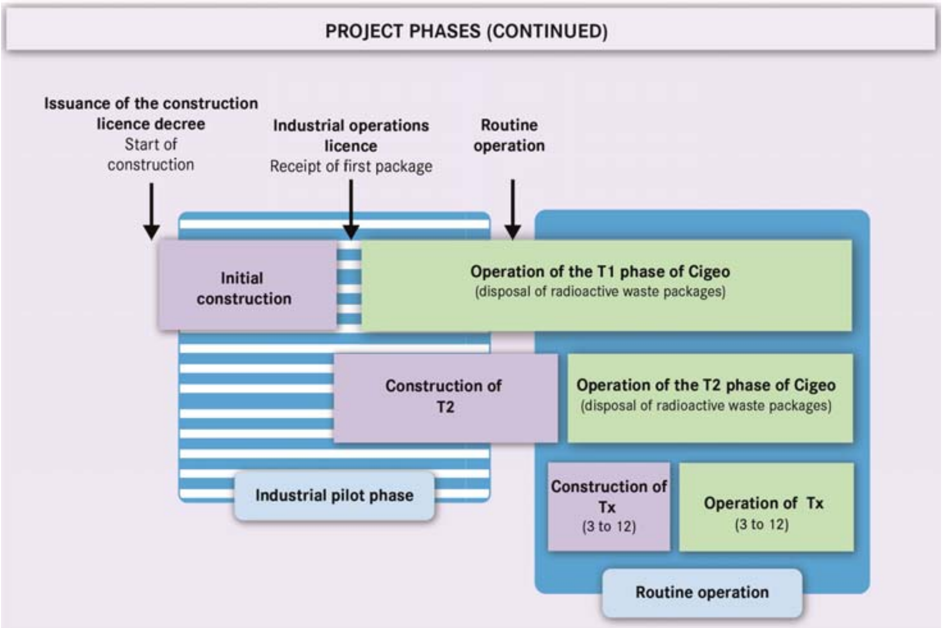

Figure 2.4-2 *Diagram showing the sequence of construction work and operating according to successive phases*

3

Safety strategy

3.1 Regulatory framework and standards

In addition to the 2006 Act, the regulations applicable to Cigeo include codes, decrees, orders and resolutions.

In the wake of the Nuclear Security and Transparency Act (known as the TSN Act) of 13 June 2006 and publication of the Order of 7 February 2012 (16), ASN launched the process of converting this Order into a series of resolutions. Some of these resolutions have been published and apply entirely or in part to Cigeo. Other resolutions are still in the process of being drawn up and are listed for the purpose of information only; depending on their scope and on whether they have been published at the time, they will be taken into consideration in the licence application.

The Table given in Appendix 1 lists the key texts taken into consideration in designing the Cigeo project.

3.1.1 Reference regulations

Regulatory texts that do not apply to Cigeo but which do apply to infrastructure analogous to the Cigeo facilities are referred to for the purposes of the facility design, given its specific nature.

Relating to fire

With regard to managing fire risk, the following texts are taken into consideration:

- the regulations relative to road tunnels, particularly Appendix 2 to Interministerial Circular No. 2000-63 of 25 August 2000, which is a prescriptive regulatory text stipulating a certain number of practical technical requirements applicable to tunnels;
- the Appendix to European Directive 2004/54 and the Order of 8 November 2006 setting out minimum safety requirements for tunnels in the Trans-European Road Network.

Regulations relating to mining

The General Regulations applicable to mining and quarrying industries (RGIE) is referred to, in addition to the regulations on mine engineering structures, including Decree 88-1027 of 7 November 1988 and, in particular, the sections on construction zones in underground facilities.

3.1.2 Draft ASN Resolutions applicable to basic nuclear installations

The Table given in Appendix 1 lists draft resolutions in progress which may impact on Cigeo and, where possible, specifies the parts and the phases covered. This Table will be updated for the licence application to indicate the final versions published by that time.

3.1.3 ASN Guides and Basic Safety Rules

The Basic Safety Rules (BSR) and guidelines relating to basic nuclear installations published by ASN are mostly applicable to surface nuclear installations. The Table given in Appendix 1 lists the BSRs and guidelines referred to for Cigeo and, in particular, identifies those parts of Cigeo to which these rules and guidelines may apply.

The ASN Safety guidelines for the final disposal of radioactive waste in a deep geological formation (17) are mainly applicable to the post-closure phase of the Cigeo project. They do include recommendations relative to the choice of site, which must take into account the mechanical and thermal properties of the rock. These properties determine the repository's feasibility, i.e. the possibility of building a repository whose effects on the geological medium are compatible with the safety objectives during the operating phase.

In a similar vein, in the chapter on waste packages, the guidelines set out recommendations regarding containment[13] to be ensured during operating and taken up in the sections on the functions to be ensured by the waste packages.

3.1.4 Industry standards

The following standards have been referred to for the design of the nuclear ventilation systems:

- *guide de ventilation des installations nucléaires* (version published in 07/1987) [ventilation guide for nuclear facilities];
- ISO 17873 Standard: criteria for the design and operation of ventilation systems for nuclear installations other than nuclear reactors.

To assess the risk of an aircraft crash for a nuclear or industrial facility, technical report SASC/86/46 *Pratique de l'évaluation du risque aérien pour une installation nucléaire ou industrielle*, J. Fauré, December 1986, (18) has been used in addition to BSR I.1.a mentioned above.

3.1.5 Andra Reference documents

Given that the Cigeo facility is so different from any other type of basic nuclear installation, Andra has developed safety standards for Cigeo and fire safety standards specific to Cigeo design which include all the approaches and requirements that have been adapted, in particular to the fact that Cigeo will be an incremental and underground project.

<u>Safety standards</u>

For the surface facilities at Cigeo, the safety standards document is based on the regulatory standards applicable to basic nuclear installations. For the underground facility, bearing in mind the type of activities that will be performed there at the same time (excavation, equipment installation, nuclear operations, etc.), a number of regulatory standards may be applicable or can be adapted: nuclear activities which come under a category relating to some of the facilities within a basic nuclear installation (INB) and the possible application of the related general technical regulations, mining and tunnelling activities regarding excavation, transfer and construction of the drifts and cells.

In developing these safety standards, Andra drew on feedback on the Andra 2005 and 2009 Dossiers (2) and (19) the examination of each. The standards also draw on changes in the regulations, including ASN publications and the Order of 7 February 2012 on basic nuclear installations (16), as well as the related resolutions and guidelines.

The key points of the approach described in the safety standards document are explained in the sections below.

<u>Fire safety</u>

In order to factor in the specific nature of Cigeo and, more particularly, a) the fact that it is an underground facility and b) that it will be developed in stages, Andra has drawn up a "*Référentiel incendie pour la conception de Cigéo*" (20) (Fire safety standards for the design of the Cigeo underground facility) which sets out the requirements regarding management of fire risks. This document is based on texts applicable to nuclear safety and the security of conventional underground structures, as well as on feedback.

In particular, it sets out the approach to be taken in the design and provision of fire risk analyses. The fire safety objectives and the basic principles underlying the design of the underground facility and the surface-bottom connections, described in the fire safety standards, are:

- to protect the lives and health of people present inside the facilities;
- to protect the environment (includes protecting the population in neighbouring areas);

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[13] These guidelines also mention that waste packages play a part in ensuring *safety at the disposal facility during the operating phase and, to the extent necessary, in ensuring facility safety post-closure.*

- to maintain safety functions;
- to maintain industrial activity and the facilities.

This document was examined by IRSN in 2014 at the request of ASN, which pronounced it satisfactory (21).

Other reference documents and guides

In addition to the two documents mentioned above, Andra has drawn up guides and methods applied within the framework of Cigeo design at the stage of the basic engineering design, which will be used for the safety demonstration. These guides and methods are based on national and international practices (for example in the case of the biosphere approach), and also on feedback.

The Table given in Appendix 2 lists the reference documents and guides developed by Andra.

3.1.6 International standards and practices (IAEA, ICRP and NEA, etc.)

Texts published by international organisations (IAEA[14], NEA[15], ICRP[16]) are standards.

The tables given in Appendix 3 list the key documents referred to at this stage in the Cigeo project.

The safety approach is in line with the texts on safety issued by the international organisations, which set out the principles pertaining to dialogue with the international community:

- some of the NEA publications deal with the links between research subjects, facility design and the safety demonstration. In Appendix 3, only the documents relative to the safety demonstration are listed;
- compliance of the facility design and the safety approach with the principles set out in "Radioactive waste disposal facilities safety reference levels", published by WENRA[17] in December 2014 has also been checked. At the stage of basic engineering design, no significant noncompliance has been observed;
- with regard to the IAEA, Andra is involved in the international GEOSAF II project, one of the main objectives of which is to list the IAEA standards applicable and/or transposable to geological disposal. The tables given in Appendix 3 present an initial list, to be updated in view of the conclusions of GEOSAF II;
- last, the Table in Appendix 3 identifies the two key ICRP publications used as references by Andra.

Andra initiated and is involved in the EG-OS[18] project under the aegis of the OECD and NEA, which aims to establish the approaches chosen and to discuss operating safety options.

The international standards and Andra's involvement in international exercises are input for the development of Cigeo and also make it possible to ensure that the safety strategy defined by Andra is in line with these standards and practices.

[14] International Atomic Energy Agency
[15] Nuclear Energy Agency
[16] International Commission on Radiological Protection
[17] Western European Nuclear Regulators Association
[18] For more information, the EG-OS (Expert Group of Operational Safety) project is presented on the NEA website https://www.oecd-nea.org/rwm/egos/

3.2 Safety principles and the safety approach

3.2.1 Principles

The key objectives for repository design are set out in the ASN's Safety Guidelines for the final disposal of radioactive waste in a deep geological repository (2008): "The fundamental safety objective assigned to the disposal of radioactive waste in a deep geological formation is the protection of human health and of the environment. This means ensuring protection against the risks linked to the dissemination of radioactive substances and toxic chemicals. After closure of the disposal facility, the protection of human health and the environment must not depend on monitoring and institutional checks which cannot be maintained with certainty beyond a limited period. "

The principle defined involves implementing, from the design stage, a safety approach and process which factor in the specific characteristics of a repository as described below:

- an underground facility located at a depth of around 500 m, of reduced geometry and long connecting drifts, requiring specific operating, intervention and evacuation conditions;
- an operating phase lasting around one hundred years, with the disposal facility being developed in successive phases, implying a need to factor in the risks related to performing underground construction work and nuclear operations in parallel;
- a coordinated approach encompassing operating safety and post-closure safety. This approach will integrate any changes in the design while ensuring post-closure safety throughout the entire development cycle of the Cigeo project.

This approach, connecting operating safety with post-closure safety, will thus enable possible optimisation and operating feedback to be managed effectively, integrating any changes in national and international regulations and practices while ensuring implementation of the principle of defence in depth. The possibility of integrating new technical solutions into the design of the disposal system will thus be confirmed, based on analysis of whether they are compatible with safe facility operating and comply with the post-closure safety requirements.

As a result, even though the post-closure phase will not be initiated for over one hundred years after the start of operating, post-closure safety analysis is developed from the initial design stage and based on projections up to the end of facility life of the technical solutions integrated at each stage of the project's development. Some of these solutions may imply a need to implement major safety-related operations as soon as construction starts and then monitor those operations identified.

Given the long life cycle of the waste disposal facility and the long radioactive half-lives of the waste, implying a multidisciplinary approach (mining and nuclear engineering, safety, the earth sciences and materials science, etc.), in order to characterise the phenomena liable to be encountered, the safety approach must identify and seek to minimise the risks during operating and the uncertainties in our knowledge.

The safety approach implemented in designing the disposal facility clearly specifies:

- the identification of the safety requirements which must be taken into account in the design. This involves:
    - ✓ identifying the standards, the regulations governing the design options and principles and which provide the framework for the safety analysis;
    - ✓ identifying the safety functions;
    - ✓ understanding the extent of knowledge regarding the characteristics of the waste and materials, the geological medium, the site, and how these all interact, and defining the objectives of protective measures,
    - ✓ understanding the characteristics of the facility and the site where it is located, mainly through the use of demonstrators;
    - ✓ in view of the post-closure phase in particular, understanding the science of the thermal, hydraulic, mechanical, chemical and radiological (THMCR) evolution of the facility over time and in space, and of the combination of these different phenomena, primarily drawing on

extensive experimentation in the Laboratory and in situ, reproducing expected evolutions and referring to natural analogues over extremely long time scales.

- the assessment stage, which must demonstrate that the design options satisfy the safety functions, by means of:
  - ✓ the safety analysis relative to facility operating, based on a risk analysis and, where appropriate, the implementation of the prevention and protection measures required to reduce the risks identified;
  - ✓ the post-closure safety analysis, based on an analysis of post-closure uncertainties by means of qualitative safety analysis which identifies and assesses, for each individual component part, the uncertainties regarding the evolution of repository behaviour as identified in the 'Phenomenological Analysis of Repository Situations' (PARS) to ensure that they are covered by design options or in the scenarios.

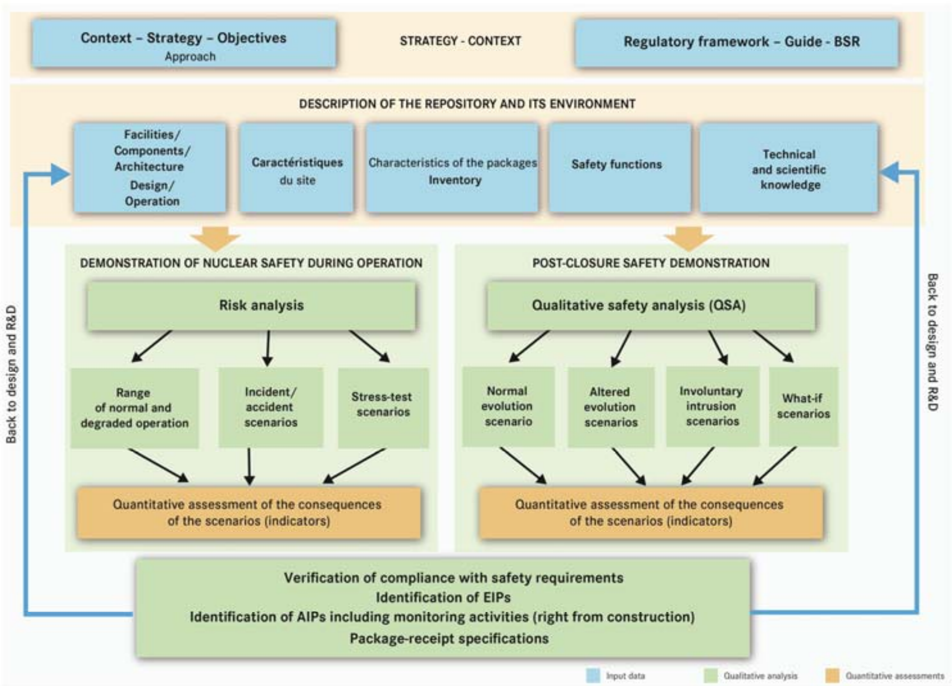

Figure 3.2-1 *Diagram showing the coordinated approach to operating safety and post-closure safety*

The iterative process implemented is in line with the ASN safety guidelines (2008) and is used to demonstrate that the choices made are acceptable insofar as regards two obligations: safety throughout facility operating and safety for the long term without the need for intervention, known as "passive safety".

The safety approach is thus an integral part of the design approach, implying that safety requirements which must be considered are taken into account in choosing the design options and checking these choices by means of assessments characterising the safety level of the repository resulting from the fact that they are taken into consideration.

3.2.2 Applying the defence in depth principle to operating safety

The concept of defence in depth is applicable to Cigeo, as it is to all basic nuclear installations, in accordance with the Order of 7 February 2012 (16). This concept is a safety principle implemented from the design stage in light of the risks involved to the population, workers and the environment, and thereby ensuring levels of safety and security which comply with the safety and radiation objectives defined.

It involves setting up an appropriate number of technical and organisational measures between a source of danger (e.g.: a radioactive or toxic substance) and the public, workers and the environment to remove or reduce to an acceptable level any possible hazard related to that source of danger. Such measures must be designed in proportion to the scale of the risks or drawbacks presented by the facility (cf. Article 1.1 of the Order of 7/02/2013 (16)).

This concept of defence in depth therefore factors in any possibility of technical, organisational or human failure, and involves setting up a series of lines of defence to protect against, manage and mitigate the consequences of internal or external hazards to the facility. It is applied as per the levels shown in Table 3.2.2, reproduced from the Order of 7 February 2012 on basic nuclear installations and INSAG-10.

Table 3.2-1 Levels of Defence in Depth

Level	Objective (22)	Essential means
1	Prevention of abnormal operation and human and technical failures	Conservative design and high quality in construction and operation
2	Control of abnormal operation and detection of human and technical failures	Design and operating provisions: control and detection systems and other surveillance features
3	Control of accidents within the design basis by means of safeguard and prevention systems and procedures	Safeguard systems and specific procedures
4	Control of severe plant conditions, including prevention of accident progression and mitigation of the radiological consequences through accident management	Measures as defined in the On-site Emergency Plan (PUI), specific equipment and emergency procedures to limit radioactive releases
5	Mitigation of radiological consequences thanks to emergency response	Measures as defined in the Off-site Emergency Plan (PPI5), emergency response organisation, measures to be taken in the event of any contamination risk and conditions relative to informing the public and the media

Implementation of the principle of defence in depth is primarily based on:

- the choice of a suitable site, mainly factoring in natural or industrial risks to the facility;
- identifying the functions required for the demonstration of nuclear safety;
- a design approach applied to Cigeo which integrates design margins and, to provide redundancy as necessary, based on adequate physical or geographical separation and diversification of the major components which provide protection and ensure the functions required for the demonstration of nuclear safety, in order to attain a high level of reliability and safeguard those functions;
- high quality design, construction and operating activities;
- preparedness relative to incident and accident management.

3.2.3 Study on operating situations

3.2.3.1 Definition of operating situations

Operating situations are defined as per the Order of 7 February 2012 on basic nuclear installations (16) in accordance with the categories described below.

<u>Normal and degraded operating situations</u>

Normal operating includes all routine states and operating of the facility, including scheduled maintenance or outage situations, irrespective of whether or not radioactive substances are present.

Operating in degraded mode involves any operating situation other than normal operating whose limited-term acceptability with regard to interests including security, public health and safety and the protection of nature and the environment, is demonstrated.

The Cigeo repository must be designed to enable the performance of operations with meet the expected functional needs. These operations will be performed within the framework of so-called normal operating situations for which the technical specifications and requirements are complied with. To ensure that functional needs are met and the requirements are complied with, design studies are carried out to define the performances required of the components and equipment used, their related characteristics and the constraints related to actions required for their operation. Once the ongoing studies are completed, the facility's operating range limits will be defined, covering normal operating and degraded operating as defined in the Order of 7 February 2012 on basic nuclear installations. The operating range will then be included in the General Operating Rules (RGE) which set out the conditions and actions provided for to maintain and, in the event of deviation, to return to normal facility operating.

In terms of safety, normal and degraded operating situations are therefore characterised using performance criteria or indicators relating to components, conditions and/or actions ensuring compliance with the safety criteria.

<u>Incident and accident situations</u>[19]

Incident and accident situations are any unplanned facility operating situations that occur during normal or degraded operation and which are liable to affect the protection of the interests of security, public health and safety and the protection of nature and the environment. This implies that the performance criteria or indicators, which underlie compliance with the safety criteria associated with these normal and degraded operating situations at the facility, have been exceeded.

Design basis incident and accident situations are situations for which facility design must:

- prevent such situations from occurring, generally implying the reinforcement of expected performance and thus of the criteria relating to component design, under the conditions and/or in the event of actions designed to ensure that safety criteria under normal operating are met;
- allow for the facility to return to normal operating, or, failing this, to attain and then maintain the facility in a safe state, which may also require the installation of specific systems;
- mitigate their impact. Additional mitigation measures are therefore designed and installed to perform this function in order to meet the safety criteria associated with the type or category of accident in question.

Incident situations are situations which occur with moderate frequency and the consequences of which for people and the environment are not serious. They are analysed with a view to designing the facility with regard to the first and second level of defence in depth (i.e. prevent such situations from occurring and allow for a return to normal operating) since, in general, they do not require measures to mitigate or safeguard against serious consequences.

[19] The potential or actual consequences of an accident are more serious than those of an incident

Accident situations are situations which occur with a frequency and with consequences that can be deemed unacceptable with regard to facility safety and security objectives in the absence of specific measures designed to manage such situations. Some of these may also be required under the applicable Basic Safety Rules. They require specific mitigation measures to be implemented at the third level of the defence in depth system.

<u>Design basis situations in the On-site Emergency Plan (PUI)</u>

These situations are used to ascertain the robustness of the facility and, if necessary, add further measures to the design basis to ensure that, in the event of a potentially serious, albeit rare, accident, the consequences will be limited in terms of time and space. They are also used to design the measures to be implemented in the case of an On-site Emergency Plan. Such situations are design basis accident situations in which an additional aggravating failure independent of the initiating event occurs, or accident situations not defined as design basis situations given the unlikelihood of ever occurring (e.g. a series of independent internal failures occurring simultaneously), situations initiated by external hazards (earthquake or flooding) which are much stronger than the relevant design basis situations.

<u>Excluded situations</u>

These are accident situations for which a large number of preventive measures, of proven robustness, are implemented (a situation whose extreme unlikelihood can be affirmed with a high degree of confidence, or situations which are physically impossible).

<u>Extreme situations</u>

These are design basis situations used in the design, where necessary, of a hardened safety core of measures within the framework of Complementary Safety Assessments (CSA). The situations that must be taken into account include earthquake, flooding, other natural phenomena and multiple hazards, loss of power and loss of cooling systems, and the hazards caused by such situations.

3.2.3.2 Identifying operating situations

The approach taken to identify operating situations is explained in Figure 3.2-1 below-.

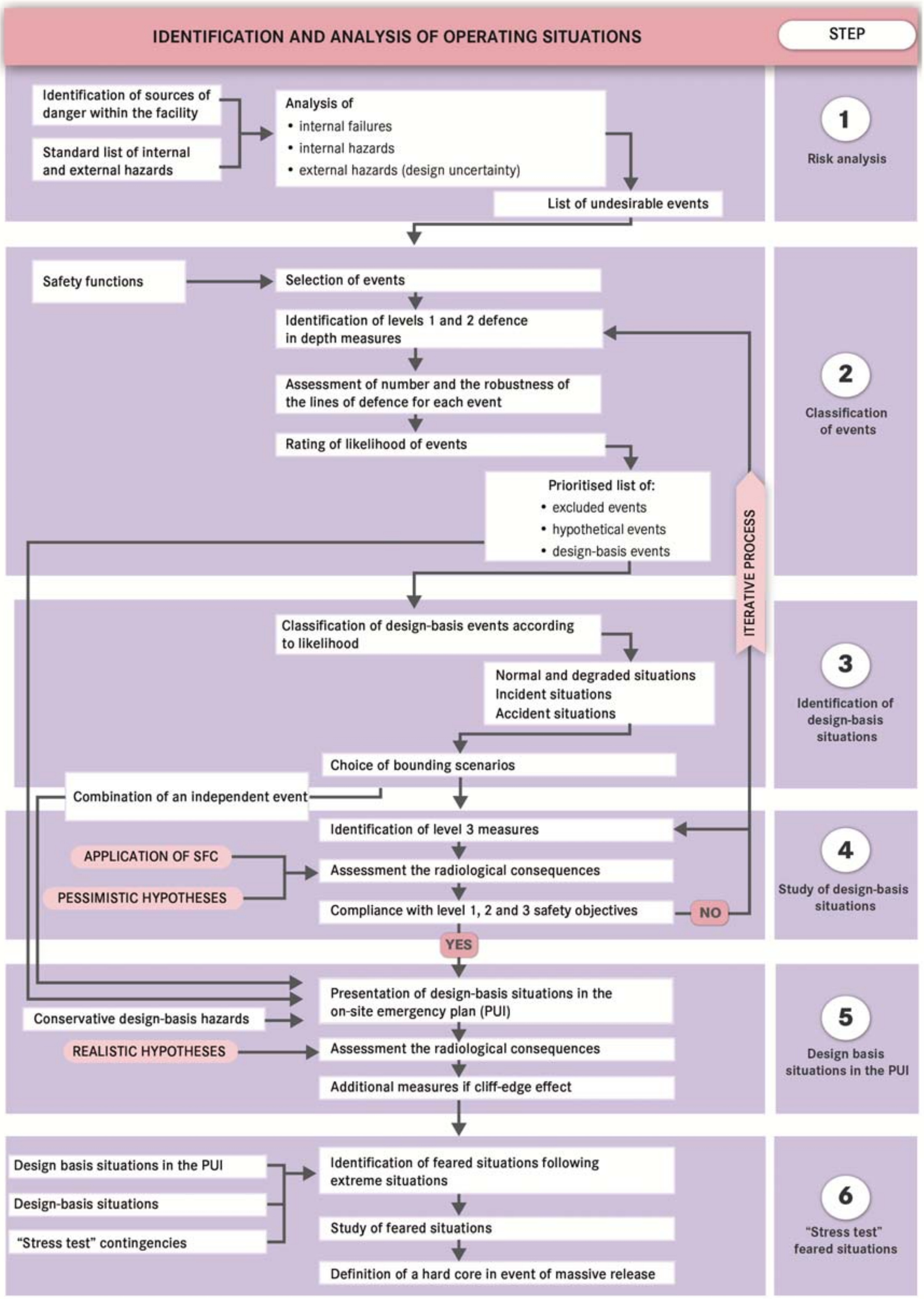

Figure 3.2-2 Diagram explaining the approach used to identify and analyse operating situations

The approach to identifying situations is a deterministic approach.

It involves:

- Step 1: analysing possible risks to the facility. The risk analysis serves to identify, based on analysis of internal failures and internal and external hazards liable to occur at the facility site, a list of undesirable events resulting in failure of equipment, procedures and related support systems, and this for all facility states. Next, for each event identified, be it nuclear or non-nuclear, of internal or external origin, the measures to be implemented to manage the risk are identified in terms of:
  - ✓ technical and organisational means to prevent incidents from the design stage, integrated in the design of facilities and proposing prevention measures and factoring in all possible equipment and human failures and external hazards;
  - ✓ the means to monitor facilities and equipment to detect any deviation in operating and correct them using automated systems or actions performed by operators, thereby maintaining the system in its normal operating mode;
  - ✓ the protective measures to be implemented to mitigate the consequences of the incident or accident operating situation at the repository which would result in a failure of preventive measures and monitoring and to reduce the severity of its consequences.
- Step 2: classifying undesirable events according to the likelihood of them occurring, in the following order:
  - ✓ events excluded on the basis of multiple lines of defence with proven robustness. No further study of such events is needed;
  - ✓ hypothetical events. such events are studied to verify the facility's robustness in the event of operating beyond its design range;
  - ✓ design basis events. These are studied to verify whether the safety measures implemented to manage the risks identified for the facility are adequate.

The likelihood of an event occurring depends on the number and the robustness of the lines of defence that must be lost for the event to occur. The lines of defence are risk control measures associated with defence in depth levels 1 and 2. Events may also be classified by taking into account expert opinions and lessons learned from operating feedback.

- Step 3: classifying design basis events according to the likelihood of them occurring during normal, incident or accident situations, and then grouping together design basis events which lead to scenarios of the same type into a smaller number of “bounding” scenarios for the family they represent.
- Step 4: studying the design basis situations to verify that the facility, by means of the measures adopted for its design, complies with regulatory requirements and the objectives defined by Andra. “Bounding” scenarios are analysed in order to:
  - ✓ evaluate the consequences for people and the environment resulting from the risk situations identified (release of radioactive substances, irradiation, thermal effects, etc.);
  - ✓ reach a conclusion regarding the acceptability of the situations studied and their potential consequences by assessing the margins between these consequences, the objectives and the regulatory limits.
- Step 5: completing this analysis by verifying the robustness of the safety demonstration by studying more complex scenarios which are the design basis situations in the On-site Emergency Plan (PUI).
- Step 6: verifying, by means of complementary assessments, the robustness of the facilities in extreme situations.

3.2.3.3 Complementary Safety Assessment (CSA)

The approach to complementary safety assessments (which may also be referred to as "stress tests") is applied to the Cigeo project and entails assessing the safety margins of nuclear facilities with regard to extreme natural phenomena, and testing facility safety functions that could lead to feared situations.

The specifications for the "stress tests" on nuclear installations drawn up by ASN (23) in the wake of the accident in Fukushima provide a guideline for integrating complementary safety assessments into the design of Cigeo.

The approach entails:

- identifying feared situations and identifying cliff edge effects for each situation (e.g. nuclear risks, chemical risks, etc.). Feared situations are identified for every phase in the facility's life cycle (operating, monitoring, dismantling, etc.), including short-term phases (maintenance), for the surface and the underground facilities at Cigeo:
  - ✓ where necessary, a "hardened core" of equipment (systems, structures and components) and organisational measures which must remain available even in extreme situations, is identified in order to:
  - ✓ prevent the appearance of feared situations or mitigate their consequences;
  - ✓ limit massive releases in the event that an accident scenario cannot be controlled;
  - ✓ ensure emergency response management;
- assessing the robustness of these measures with regard to extreme situations liable to result in such feared situations:
  - ✓ extreme situations to be taken into account:
    - earthquake, flooding, other natural phenomena, multiple hazards;
    - loss of power, loss of cooling systems;
    - induced hazards;
  - ✓ characterise the hazard levels of such extreme situations ("stress test" hazard levels). These are defined as hazards which are significantly more dangerous than those used for the design basis;
  - ✓ design systems, structures and components (SSC) in relation to the "stress test" hazard levels;
- defining the emergency response management procedures for the entire site. This means the actions and measures developed to manage the response to feared situations in the event of an extreme situation at the site. It is also at this level that hazards caused by surrounding facilities are studied to assess their possible impact on the emergency response management measures implemented;
- taking account of organisational and human factors, and the use of outside service providers. This entails specifying the role of the different players that may be called on to respond in the event of an emergency, and how they are monitored and the resources and procedures used.

3.2.3.4 Assessing the radiological consequences

<u>Assessing the radiological impact in normal and degraded operating situations</u>

Doses received by the population are estimated using assumptions that are as realistic as possible (forms of releases, weather conditions, waterway flow rate, etc.). Received doses are estimated for one or more reference groups for three age categories (infants, children and adults) and factoring in the various transfer pathways of radioactive substances (liquid and gaseous releases).

The transfer pathways to be considered include:

- external irradiation;
- intake of radionuclides, indicating their nature and, where necessary, their physical and chemical states.

Assessing the radiological consequences of incidents and accidents

The design basis incident and accident situations are analysed using the "bounding" assumptions with regard to (radiological, physical and chemical) consequences. This requirement aims to:

- ensure that the "bounding" situations defined encompass all similar situations (same conditions, same initiating event) liable to arise;
- provide safety margins related to the criteria required to cover any uncertainty related to the phenomenology of the events in question.

The single failure criterion is applied to assess the consequences. This is performed:

- for the workers: the effective doses associated with releases of radioactive substances are assessed by calculating exposure caused by the plume (external irradiation and inhalation);
- for the public: as for the workers;
- for the reference group: for this type of population, the effective doses associated with releases of radioactive substances are assessed by calculating exposure caused by the plume (external irradiation and inhalation), external exposure caused by fallout and the ingestion of contaminated foodstuffs.

Assessing the radiological consequences of the design basis situations in the PUI

The design basis situations defined in the PUI are studied using "realistic" design assumptions. These situations are used to ascertain the robustness of the facility and, if necessary, add further measures to the design basis to ensure that, in the event of a serious, albeit rare, accident, the consequences will be limited in terms of time and space. Notwithstanding, it may be necessary to err on the side of caution in the case of the parameters that predominate as the accident unfolds.

Assessing the radiological consequences of extreme situations

As for the design basis situations in the PUI, extreme situations are studied using "realistic" design assumptions linked to extreme natural hazards exceeding the levels considered in the aforementioned situations, combined with the postulated loss of certain utilities.

3.2.3.5 Assessing non-radiological consequences

The intensity of non-radiological hazardous phenomena is defined in relation to benchmark values expressed in the form of toxic effects, overpressure effects, thermal effects and effects linked to the impact of a projectile for people and structures. The benchmark values used are those given in Appendix II of the Order of 29 September 2005 (24).

Risk analysis for buildings in which hazardous substances are stored or handled is carried out to define any scenarios that could result in dangerous phenomena.

The impact on people liable to be exposed in the scenarios defined is then assessed to ensure that the intensity of hazardous phenomena does not exceed the irreversible effects threshold (SEI) for people (See Appendix II of the Order of 29 September 2005):

- SEI for toxic effects;
- 50 mbar for overpressure effects;
- 3 kW/m^2 for thermal effects.

3.2.4 Establishing elements and activities important for protection (EIP/AIP)

3.2.4.1 Definitions of EIP and AIP

- ***EIP***

The Order of 7 February 2012 on basic nuclear installations sets out the rules on taking account of the risks and drawbacks of INBs with regard to the protection of interests. The risks are related to facility operating in the event of an accident, meaning radiological and non-radiological risks, and the drawbacks are defined for normal and degraded operating modes.

Controlling risks and drawbacks leads to the definition of three types of "elements important for protection" (EIP):

- EIPs linked to radiological accidents identified based on the safety analysis report studies for the INB;
- EIPs linked to the risk of non-radiological accidents identified based on the safety analysis report studies for the INB;
- EIPs linked to the drawbacks identified based on the impact study or required under orders and resolutions relative to releases.

EIPs linked to radiological and non-radiological risks are identified along with the elements taken into consideration in the demonstration of nuclear safety:

- they are directly involved in implementing and maintaining a protection function, or in controlling it, and include support elements for the latter (i.e. elements that ensure that they function, for example, the electricity supply or fluids, etc.). They are identified on the basis of the study on incident and accident scenarios which focuses on the technical and/or organisational measures implemented to control the risks identified;
- they are not directly involved in a protection function but, in the event of failure, would lead to the loss of a protection function. They are identified on the basis of an analysis of failures, which indicates the importance of a structure, equipment or component as initiating an incident or accident. They are selected on the basis of the direct consequences generated by the element's failure.

We should also include elements which protect the elements identified above or which, if they fail, may cause damage to them.

EIPs linked to drawbacks are identified, in proportion to the drawback, among the measures designed to:

- comply with regulatory requirements and limits. The data used for the purposes of identification are included in the impact study (avoidance and mitigation measures) and in the regulatory texts relative to water intake and discharge permits and to pollution;
- detect any instance of exceeding the regulatory limits;
- stop an abnormal situation.

Elements that support EIPs linked to drawbacks are also identified.

The requirements defined in relation to EIPs are assigned to these elements to ensure that they fulfil, with the expected characteristics, the expected function(s) regarding the protection of interests. The requirements defined are therefore described in terms of performance and/or reliability:

- in the ambient conditions in which the EIP performs its function (in normal, degraded, incident and accident mode);
- taking into account any stress to which the EIP is subject in the conditions (normal, degraded, incident or accident) in which it is required to perform its function.

▪ ***AIP***

Activities important for protection (AIPs) include:

- AIPs linked to EIPs: this includes design, testing, in-service monitoring, periodic inspections and tests, and maintenance measures associated with qualifying all EIPs;
- AIPs that are not linked to EIPs but are involved in demonstrating the protection of interests. For example, activities including environmental monitoring, dealing with anomalies, or managing changes to the facility.

Activities important for protection (AIPs) during operating and linked to elements important for post-closure safety (EIPs) perform control and monitoring actions.

In the specific case of the Cigeo project, to achieve the basic objective to protect people and the environment in the long term, which depends on the fundamental role of Callovo-Oxfordian clay rock (5), the control and monitoring actions to be implemented in the construction and operating phases of the facility must also be identified.

Elements that are important for the post-closure phase are identified at the design stage in the Safety Options Report – Post-Closure Part (DOS-AF), together with the activities to be implemented. For example, the need to control the intensity and extent of any disruption caused by excavation, emplacement and in the event of an accident liable to alter the transport and retention properties of the Callovo-Oxfordian layer.

3.2.4.2 Qualifying EIPs

Article 2.5.1 of the Order of 7 February 2012 stipulates that EIPs must be qualified to ensure compliance with the requirements defined (requirement assigned to an EIP to ensure it fulfils the function defined in the demonstration of nuclear safety with the expected performance characteristics). For Cigeo, this qualification will also be performed for as long as necessary to demonstrate that the interests are protected.

Thus, for each EIP, the qualification approach is based on:

- an initial qualification of the EIP. This includes design, construction and test measures used to demonstrate compliance with the defined requirements;
- verification that the initial qualification remains valid. This includes in-service monitoring, inspection and maintenance once the element is in operation.

Certain activities linked to EIP qualification are considered to be AIPs. In the case of passive elements which cannot be subject to maintenance and control measures (e.g. impossible to access), the initial EIP qualification will provide, with a sufficient degree of confidence throughout the required period, as per the demonstration, a guarantee that the defined requirements are met.

3.2.5 Methods and tools for the safety demonstration

Specific methods are presented for each risk (criticality, handling, etc.) in the relevant chapters in Volume III of this Report. In general, Andra applies the provisions of the Order of 7 February 2012, particularly those set out in Article 3.8 relative to computing data, methods and tools and modelling. The systems and sub-systems engineering contractors apply these provisions which are rendered applicable to them under contract.

3.3 Safety functions

The five safety functions described below are applicable to Cigeo throughout the operating phase and must be maintained in all incident or accident situations of internal or external origin or, at least, restored within time limits consistent with the objectives of protecting people and the environment defined for the Cigeo project.

- contain radioactive substances to protect against the risk of their dispersion;
- protect people from exposure to ionising radiation;
- manage safety with regard to the criticality risk;
- remove the heat produced by waste;
- remove gases formed by radiolysis in order to manage explosion risks.

Throughout the operating period, achieving the objectives to protect people (workers and the public) and the environment depends on effective management of the risks resulting from the radioactivity of the waste. Risk management is achieved by the performance of the nuclear safety functions mentioned above which apply to all operations during the operating phase. These safety functions and related principles are presented below:

-Contain radioactive substances to protect against the risk of their dispersion

The risk of dispersion of radioactive substances in the Cigeo facilities results from the possible dissemination of the radioactive substances contained in the waste packages during reception, lifting and handling, conditioning, transfer and emplacement of these waste packages. The packages, the facilities and the operating processes are designed to ensure that contamination levels are kept as low as possible in the facility premises and that any release of radioactive substances outside the facility is limited to ensure the protection of the personnel, the public and the environment in all operating situations.

Managing the risk of dispersion implies setting up a series of different containment barriers between the radioactive substances and the environment (in accordance with Article 3.4 of the Order of 7 February 2012 (16). The following principles are applied:

- in normal operating conditions, the packages, the facilities and the operating processes are designed to ensure that contamination levels are kept as low as possible in the facility and that any release of radioactive substances outside the facility is limited;
- in incident or accident situations, the design aims to limit the radiological consequences for the personnel, the public and the environment by preventing any contact with radioactive substances and particles which are not contained;
- in addition, and in addition to the measures implemented to prevent accidents, in the case of possible dissemination of radioactive substances, the measures applied to mitigate such risks also imply defining measures to contain any activity which might be released as close as possible to the source of emission in zones specifically designed to contain or, failing this, to channel and filter any radioactive release.

These principles are complied with in the choice of technical and safety options for Cigeo, in line with the following rules:

- two independent containment barriers are set up for normal operating situations;
- at least one containment barrier is maintained in incident and accident operating situations.

Protecting people from exposure to ionising radiation

In addition to meeting the radiation protection objectives defined in Section 3.4, the Cigeo facilities are designed according to the radiation protection optimisation approach known as the ALARA principle, standing for "As Low As Reasonably Achievable", in line with the principle introduced by the ICRP and taken up in Article R.4451-10 of the French Labour Code and Article L.1333-1 of the French Public Health Code. After characterising the risks of exposure, this radiation protection optimisation approach is used to assess the performance of the radiation protection "options" (procedures and technical measures) and select those that will be implemented, bearing in mind exposure and also other factors, such as the implications regarding safety and security and the impact on the environmental, etc.

Radiological protection measures for the Cigeo facilities are designed and assessed in line with the "*Méthodologie pour la conception et le dimensionnement des moyens de protection*" (Methodology used in the conceptual and structural design of protective systems) recommended by Andra. This methodology is based on feedback on current practices implemented for the design of basic nuclear installations.

Managing safety with regard to the criticality risk

At the design stage, construction requirements (controlling geometry and mass) are given priority over operating instructions, in order to reduce risks related to human and organisational factors. The criteria applied are:

- keff + $3\sigma \leq 0.95$ in normal situations;
- keff + $3\sigma \leq 0.97$ in incident and accident situations.

Removing heat from the waste

To protect operators from the risk of burns during the operating and reversibility period, the temperature of hot walls to which they have access must be kept below 50°C.

To protect electronic equipment used to perform or monitor safety functions, the ambient temperature of the air in the rooms containing such equipment or, at least, surrounding electronic equipment, must generally be below 50°C. This limit may be revised in individual cases depending on the equipment used or specific implementation conditions (e.g. in HLW disposal cells).

In addition, the underground facility is designed so that the removal of heat released from waste packages placed in the disposal cells can be performed by passive conduction within the rock, as soon as waste is emplaced in the disposal facility. During operating, this primarily applies to temperature criteria related to:

- conserving the mechanical properties of the concretes used (temperature kept below 65°C during normal operating (permanent) and below 80°C during an incident situation);
- controlling the behaviour of radionuclides in the case of a cell used for the disposal of non-exothermic or slightly exothermic waste (temperature kept permanently below 70°C);
- protecting the clay rock (temperature below 90°C).

Support structures must be designed bearing in mind the length of time for which the support and liner concretes will be subject to such temperatures in order to reduce the risk of deterioration to the concretes.

In some drifts and zones, the presence of temperature-sensitive equipment (sensors, embedded or autonomous equipment, etc.) will require the application of criteria regarding the temperatures corresponding to the range in which it can be used.

<u>Removing gases formed by radiolysis in order to manage explosion risks</u>

Radiolysis of the waste produces gas. The main gas produced is hydrogen.

When substances liable to form an explosive mix are inflammable gases or vapours, they must be kept at concentrations as low as possible.

In the case of hydrogen, the lower explosive limit (LEL) is 4%. In order to avoid having to design explosion-protection equipment and/or facilities, Andra applies an LEL margin for the design of Cigeo and has set the following objectives:

- in normal operating mode, to maintain a turbulent ventilation regime to prevent dead zones (zones in which hydrogen might accumulate) inside the disposal cells;
- at all times, to remain below:
  - ✓ 25% of the lower explosive limit (LEL) in all the facilities (1% hydrogen) in normal operating situations;
  - ✓ 75% of the LEL (3% hydrogen) in incident and accident situation.

3.4 Radiation protection objectives

Andra's approach is based on the recommendations issued by the International Commission on Radiological Protection (ICRP) applicable to radioactive waste disposal facilities. The principle of constrained optimisation of protection based on dose constraints, taking economic and social factors into account (ALARA), applies to the protection of personnel and the public with regard to ionising radiation throughout the operating phase of the Cigeo facility. The concepts of what is meant by "dose", used in the context of radiation protection, are defined in the French Public Health Code (R. 1333-8 and R. 1333-10) (25) (26).

Three types of population group are considered:

- regulated workers: meaning people who work in regulated zones (regulated in relation to radiation protection). They can therefore be considered as being in the immediate proximity of a radiological event;
- the public/non-regulated workers: these are people who are likely to be in the vicinity of the INB (the public) at the time of an event occurring at the INB (e.g.: at the visitors' centre, or walking close to the fencing) or (non-regulated workers) who work at the INB. Visitors and non-regulated workers do not need to be considered in the assessment of the consequences of an event provided that all measures have been taken to ensure that they are not present when high-risk operations are performed or, where this is not the case, if protection measures are implemented should an event occur;
- the reference group: a group of individuals for whom exposure to a source is more or less uniform and representative of that of individuals who, among the population, are more significantly exposed to the source in question (French Public Health Code - Appendix 13-7).

For Cigeo, the objectives relative to protection in normal and degraded situations, together with those applying to incident and accident situations, are presented in Table 3.4-.

Table 3.4-1 Objectives relative to protection against radiological risks

<table>
<tr><th></th><th>Regulated worker in a regulated zone</th><th>Public/reference group and the environment</th></tr>
<tr><td>Normal and degraded situations</td><td>ALARA
dose < 5 mSv / year</td><td>No unplanned releases
Planned releases subject to release permit
dose < 0.25 mSv / year</td></tr>
<tr><td>Incident situations</td><td>ALARA dose < 20 mSv / year</td><td>Dose lower than regulatory value (< 1mSv / year)</td></tr>
<tr><td>Accident situations</td><td>limiting doses received by workers factoring in constraints related to post-accident situation</td><td>Dose < 10 mSv (received over 50 years)
No need for measures to protect the public</td></tr>
<tr><td rowspan="2">Design basis situations in the PUI</td><td colspan="2">No cliff edge effect</td></tr>
<tr><td></td><td>Public protection measures limited in terms of time and space</td></tr>
</table>

3.5 Safety management

3.5.1 Organisation of safety management as part of the integrated management system (IMS)

Andra has set up a management system which meets the requirements of ISO 9001, ISO 14001 and OHSAS 18001(health and safety) standards. This integrated management system meets the requirement to protect the interests cited in Article L.593-1 of the French Environment Code. Andra's management system must demonstrate its ability to regularly provide a product or service which meets customers' expectations and complies with the applicable legal and regulatory requirements, and which aims to improve its customers' satisfaction.

Andra's management system is applied to the Cigeo project. Furthermore, a management plan for the Cigeo project was drawn up for the basic engineering design phase. This defines the rules applicable to the organisation, development and management of the project design phases, in particular with regard to management of the systems and sub-systems engineering contractors. The key provisions applied to ensure that the requirements to protect the interests cited in Article L.593-1 of the French Environment Code are systematically taken into consideration in all decisions relative to Cigeo are described below.

Andra has developed the specifications for systems engineering contract management, which specify the requirements relative to project performance, organisation and management with which contractors must comply. Safety analyses and design studies for elements important for protection of the interests cited in Article L.593-1 of the French Environment Code are categorised as "activities important for protection". The approach used to identify elements important for protection is presented in a specific document and is applicable to all engineering contractors (systems and sub-systems).

In response, the engineering systems contractor has drawn up a nuclear safety plan which sets out the organisation implemented to perform activities important for protection and describes the safety management processes. The systems engineering contractor has developed specifications for sub-systems engineering contractor management, including the requirements relative to safety management. Each sub-system engineering contractor has also drawn up a nuclear safety plan. These documents specify the organisation set up by the sub-system engineering contractors to perform activities important for protection.

In addition, the systems engineering contractor, in its nuclear safety plan, sets out the methods to be used in developing the safety studies and, where specific methods are not required, calls attention to the requirement regarding the qualification and validation of design codes In this last case, the procedure used for qualification and the related records are made available for the purposes of the project. In response, the sub-system engineering contractors have specified the measures implemented to demonstrate their compliance with these requirements in their nuclear safety plans.

3.5.2 Managing the requirements

In 2011, Andra compiled together all the requirements applicable to the Cigeo project, organised according to the functions required of Cigeo (disposal, safety, reversibility, monitoring, etc.). They are based on feedback on Dossier 2005 and Dossier 2009 and on the assessments thereof, as well as on the potential improvements identified.

Thus, in order to launch studies for the development of the Cigeo design, Andra has consolidated information in the form of applicable requirements for the project:

- regulatory requirements, safety guidelines that are directly applicable to Cigeo (e.g. ASN 2008 safety guidelines) and standards compiled by Andra by adapting regulations and practices not directly applicable to Cigeo (e.g. fire standards), requirements and recommendations expressed by project stakeholders and clients (French government, waste generators, assessment bodies, local stakeholders) and the social and political demand for reversibility;
- the results of studies and research conducted since 1991. In particular, this has involved transposing long-term safety objectives into design options that constitute input data for the studies to be conducted by contractors and for the technological tests.

The operating safety requirements are, in general, similar to those applicable to basic nuclear installations, except that they factor in the specific nature of the Cigeo disposal facility (lengths of connections and drifts, underground construction work being carried out in parallel to nuclear operating, operating phase of around a hundred years, specific emergency response and evacuation conditions, etc.).

The applicable requirements presented in a specific document are then used as the basis for the required technical specifications for the design of the Cigeo facility.

Verification that the requirements to protect the interests cited in Article L.593-1 of the French Environment Code is part of the design control process. Design control is continually performed within the framework of project performance management, coordinated by the manager in charge of systems engineering. Design control is also performed at the time of meetings held to review progress on the project. It is consolidated by project reviews planned at the end of each phase.

Activities important for protection performed by sub-system engineering contractors are subject to technical control and random checks carried out by the systems engineering contractor. The latter will draw up a programme of technical controls and checks and is responsible for its performance.

In addition, the systems engineering contractor is subject to a monitoring programme performed by Andra and the sub-systems engineering contractors are monitored by the systems engineering contractor, with Andra's participation. The organisation for monitoring the contractors will be presented in the draft notice presenting the technical and financial capabilities.

3.5.3 Internal and external review process

In addition to a requirement review process, as mentioned in Section 6.2, Andra has set up a system of internal reviews specifically for the analysis of data, models and safety choices to be applied to safety assessments. These reviews will serve to validate the reasons given to support the choices proposed.

The Andra Scientific Council, set up by Decree, is responsible for issuing opinions and recommendations on the priorities of the research conducted by Andra and assessing the results, primarily with regard to the issues of developing and using scientific and technological knowledge for the design and safety of the disposal system. The members of the Scientific Council are experts appointed by Andra's supervisory ministries. To this end, the Scientific Council has systematically examined all or part of the reports produced to date.

Andra has also been concerned to submit certain design and safety studies for independent assessment where this has been deemed appropriate. For this purpose, in 2012, it set up a safety committee made up of safety experts from outside the Agency. Furthermore, the development of the Cigeo project is subject to a design review process at every key stage ((conceptual design, basic engineering design, detailed engineering design, etc.) which also involves outside experts.

Set up under the Act of 30 December 1991, the CNE (National Assessment Board) assesses the quality of Andra's research programmes and produces an annual report in which it gives an opinion on this research. These opinions and recommendations are input data used to refine the research programme’s priorities.

Since 1991, as part of the Cigeo project development process, Andra has submitted a series of interim reports to ASN, which has issued opinions and recommendations with a view to the licence application. ASN also carries out "monitoring inspections, primarily at the Meuse/Haute-Marne Centre, during which it assesses the quality of the work in progress, especially at the Underground Research Laboratory.

Last, to check consistency with international practice, at the request of Andra's supervisory ministries, two peer reviews were organised in 2002 and 2005 by the OECD’s Nuclear Energy Agency. At the request of ASN, a review is scheduled for 2016, under the aegis of the IAEA.

3.5.4 Integrating organisational and human factors (OHF)

3.5.4.1 Organisational and Human Factor management principles and framework for Cigeo

The following principles are applied in OHF studies:

- develop a shared corporate culture;
- make safety a top priority;
- provide meaningful work;
- empower people so that they feel involved in the overall process;
- allow sufficient time to perform the work;
- minimise strenuous working conditions;
- optimise operational time.

These principles, which are interlinked, provide criteria, challenges and consequences to be taken into account in most decisions regarding work organisation, ergonomic design of workstations, man-machine interfaces, recruitment and training policy, etc.

In addition to the systematic implementation of these principles, OHF choices and requirements are characterised on the basis of:

- selecting OHF core standards, generic yet specific to the nuclear industry;
- using feedback, generic and specific to the nuclear industry.

3.5.4.2 The core standards

Many of the OHF requirements are found in standards and guidelines considered as standards. These collections of standards and guidelines on ergonomic design and organisational and human factors cover the following subjects:

- design of machines and workstations: general principles, dimensions and body posture, man-machine interface, physical strain and lifting and carrying, hazard signs, hot surfaces;
- ambient factors and the work environment: lighting, heating, size of passageways, size of access openings;
- control centres (rooms);
- office work spaces;
- software ergonomics.

The sources that publish recommendations and practical guidelines on the subject of OHF and ergonomic design, as well as the "core standards" documents applied to Cigeo (i.e. not including the regulatory documents) are given in Appendix 4.

During the detailed engineering design phase, checks will made to ensure that organisational and human factors are integrated appropriately in the Cigeo project.

VOLUME II DESCRIPTION OF WASTE PACKAGES, THE FACILITY AND ITS ENVIRONMENT

1

ILW-LL and HLW waste packages

1.1 Sources of waste and types of waste family

From the start of research on deep-geological disposal of high-level and intermediate-level long-lived waste, Andra and waste generators agreed to establish a unique identifier for each family of HLW and ILW-LL waste package.

By definition, a package family is a set of packages with similar characteristics (particularly their method of fabrication, chemical and radiological content, decay heat, and irradiation level) in terms of the uses made of these characteristics. The package families to be emplaced in Cigeo are therefore greater in number and more detailed than those used in France's national inventory. This is because the level of accuracy required for these two exercises is not the same. However, each package family to be emplaced within Cigeo belongs entirely to the same family in the national inventory.

Waste is generated primarily by:

- Consecutive generations of nuclear power reactors:
  - ✓ The first generation consisted of nine gas-cooled reactors (GCR) at CEA's Marcoule site and EDF's Chinon, Bugey, and Saint-Laurent sites. These reactors are no longer in operation.
  - ✓ The second generation, still in operation, comprises 58 pressurised water reactors (PWR) located at 19 sites. The very first PWR reactor, the Chooz A, is currently being dismantled.
  - ✓ The third generation is the Flamanville EPR (European Pressurized water Reactor) currently under construction.

Also included are the Brennilis (EL4) heavy water reactor and the Phenix and Superphenix fast neutron reactors (SFR). These prototype reactors are no longer in operation.

- Fuel cycle facilities. Uranium enrichment, nuclear fuel fabrication, and the reprocessing of this fuel following its use in reactors are carried out in various facilities operated by Areva. Reprocessing consists in separating uranium and plutonium, which are reusable, from the waste, consisting of fission products and minor actinides (americium, curium, neptunium), contained in fuel pellets as well as structural elements making up the metal frames of fuel assemblies.
- CEA facilities. CEA conducts its research on the design of next-generation nuclear systems and radioactive waste management, particularly for France's nuclear power programme, at a host of facilities. Examples include the Rapsodie prototype fast neutron reactor and the Orphée and Osiris experimental reactors, as well as research laboratories on fuel types and the back end of the fuel cycle, such as Atalante. Most of these facilities are located on CEA's Cadarache, Saclay, and Marcoule sites. These sites also have support facilities for the storage and processing of waste and effluents. Some are no longer in operation or are being remediated and dismantled.
- New facilities that have obtained a construction licence. In addition to the Flamanville EPR, Cigeo's inventory includes waste from the Jules Horowitz (JHR) experimental reactor, the RES experimental nuclear-propulsion reactor, and the ITER at Cadarache.

1.1.1 Assumptions used for the waste inventory

In order to draw up a qualitative and quantitative inventory for Cigeo, the industrial scenario for the operation of nuclear facilities adopted in the industrial waste management programme (PIGD (27)) established jointly by Andra and waste generators is as follows:

- In terms of the nuclear power reactor fleet, this scenario assumes the continuation of the nuclear power production with the reprocessing of all types of spent fuel from the PWR and SFR (Phenix, Superphenix) nuclear power plants. The typical useful service life of all reactors, including the Flamanville EPR, 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, nor replacement of the fleet by Generation III reactors (EPR) and/or by Generation IV reactors. It considers that the substances (uranium and plutonium) not reused in the 58 PWR reactors currently in operation and the Flamanville EPR may be reused in future facilities. Waste generated by a potential future reactor fleet is not taken into account.

As for fuel reprocessing facilities (Areva plants), the adopted scenario considers that, by convention, they align their service life 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[20], have an expected service life of 50 years. The ITER reactor is expected to operate for only 20 years.

1.1.2 Distribution of the ILW-LL and HLW waste package families

One of the specific features of the waste packages intended for Cigeo is the coexistence at this stage of four different levels of advancement in the production of waste packages. These levels may continue after the construction licence application:

- Waste packages that have already been generated[21] and which must be accommodated for by the design the repository.
- Waste packages that are currently being generated and for which a conditioning method and a package production specification have been defined.
- Waste packages that have not yet been generated but for which the definition of the conditioning method is already well advanced.
- Waste packages that have not yet been generated and for which the conditioning method is still at the research stage.

All the waste package families intended for Cigeo and belonging to these four categories are listed. More particularly, Cigeo's design is based on knowledge provided by waste generators about the safety functions to be ensured for the waste packages under each of the facility's operating conditions as well as the uncertainties following its final closure.

The basic engineering design of Cigeo and the safety studies use as an input datum the inventories, in terms of the number of packages, in the prevailing version of the Industrial Waste Management Programme (PIGD), i.e. revision D. The inventory of some waste families will be altered in a subsequent version, while the inventories of some specific types of waste[22] are already taken into consideration. The teachings of the scenarios and the adopted safety options thus will not be affected by a change in the PIGD.

[20] In this document, the term 'operations waste' denotes waste generated by operations.
[21] Some families are defined by a production specification.
[22] Vitrified waste packages that do not conform to their generation specification, CSD-RU, etc.

The concept of production status is related to the package family, not the packages themselves. It should also be noted that:

- When a waste family contains primary packages that have already been generated but which must be placed in drums before being shipped to Cigeo (e.g. bituminised waste from Marcoule), the generation of this family is deemed 'generated'.
- When a waste family contains primary packages that must be reconditioned, particularly if the primary container is defined by the generator as "to be determined", the generation of this family is deemed "to come".

There are 79 ILW-LL waste package families. ILW-LL is primarily structural waste from the reprocessing of spent fuel (35% of ILW-LL packages), waste from the reprocessing of liquid effluents from nuclear facilities (35% of ILW-LL packages), and activated technological waste (5% of ILW-LL packages) or contaminated technological waste (23% of ILW-LL packages) from the operation or dismantling of nuclear facilities.

There are 19 HLW waste package families. HLW consists primarily of vitrified waste (99.5% of HLW packages).

1.1.3 Cigeo input data on package families

Knowledge on the packages intended for Cigeo is provided by waste generators to Andra, which integrates it into its knowledge base.

Cigeo's basic engineering design uses as an input datum the package families that have been defined and quantified in the prevailing version of the Industrial Waste Management Programme (PIGD), i.e. revision D. Cigeo's detailed engineering design will be conducted using revision E of the PIGD.

The safety options are based on the identification of the design characteristics that make it possible to factor in all the families and thus cover an entire operating range. These characteristics are presented in the final section of this chapter.

Any new developments in knowledge of waste packages that are provided by waste generators will be assessed, particularly in terms of its impact on the design of technical solutions.

In terms of family type, only waste families for which no conditioning method is currently known may be modified in a subsequent version[23]. The approach implemented by Andra to establish the design characteristics and acceptance specifications will remain unchanged. Therefore, any new families will have to conform to these specifications and their characteristics will have to be covered by design characteristics. In terms of quantification (number of packages), the adopted safety options are not affected. .

1.1.4 Provisional delivery terms

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

In any case, HLW1 and HLW2 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.

[23] The amount of some specific waste packages (vitrified waste packages that do not conform to their generation specification, CSD-RU, etc.) have already been taken into consideration.

At the same time, it is envisaged that HLW0 and ILW-LL waste packages will be emplaced right from commissioning. The rate at which waste packages will be received will be gradually ramped up.

Waste generators define the provisional shipping schedule. These data, presented in the prevailing version of the PIGD, are used by Andra during the basic engineering design as input data in Cigeo's design, particularly regarding workflow management. They will be updated in the detailed engineering 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 according to a process that is currently being developed (see Volume II, Chapter 4).

The adopted safety options are independent of the delivery schedules.

1.2 ILW-LL waste package families

1.2.1 Families of structural waste packages generated by the reprocessing of spent fuel

- ***Packages of cemented hulls and end caps from Areva/La Hague (CEC) (COG-040)***

In accordance with specification 300 AQ 25, structural waste was cemented inside stainless steel drums from 1990 to 1995. This method was replaced by compacting in 2002.

- ***Compacted waste packages (CSD-C) from Areva/La Hague (COG-070 COG-100, COG-110 COG-120, COG-450, COG-530, COG-540, COG-550)***

Since 2002, structural waste from the spent fuel of pressurised water reactors is compacted and conditioned in standard compacted waste containers (CSD-C). CSD-C packages currently generated (COG-100 and COG-110) come from the in-line compacting of structural waste resulting from the reprocessing of UOX fuel and the retrieval of structural waste stored underwater in drums, and structural waste stored in metal drums in pools S1, S2, and S3 at the La Hague site. A small number of these packages also includes solid metal operations waste that has been compacted.

In years to come, such package will also be composed of waste stored in the HAO (High Oxide Activity) facility (COG-070) as well as structural waste from the future reprocessing of mixed UOX, URE, and MOX fuel (COG-120), fuel from the Phenix and Superphenix fast neutron reactors (COG-450), fuel from the CEA and from the Brennilis EL4 reactor (COG-530 for CEA/Civil, COG-540 for CEA/DAM and COG-550 for EL4).

- ***Packages of cemented metal structural waste from Marcoule (CEA-1050)***

This family encompasses metal structural waste from fuel other than from the GCR reactors (Phenix fuel, Osiris fuel, etc.), which is reprocessed at the UP1 plant (Marcoule). Based on the fuel type, this waste comprises various materials (aluminium, stainless steel, nickel alloy, zirconium-tin alloy). It will be retrieved as is, placed into 380-l drums, and immobilised in a cement matrix.

- ***Packages of magnesium structural waste from Marcoule (CEA-1060)***

Magnesium structural waste consists of cladding and end caps (or tips) from the GCR reactor fuel reprocessed at Marcoule. According to the assumption currently adopted by CEA, this waste will be retrieved, conditioned, then immobilised in 223-l stainless steel drums. The material that will be used to immobilise this waste is currently being defined.

1.2.2 Waste package families generated from the operation and decommissioning of nuclear power reactors

- ***Activated waste packages from EDF reactors, excluding sodium waste (EDF-080, EDF-090)***

These waste types contain miscellaneous components exposed to the neutron flux while in a reactor. They include activated operating waste from pressurised water reactors (PWRs) currently in operation (EDF-080) and activated dismantling waste from first-generation reactors and non-sodium-bearing dismantling waste from the Superphenix fast neutron reactor (EDF-090).

- ***Packages of pins from the control rods of fast neutron reactors - RNR (EDF-250, CEA-380)***

Boron carbide pins (B4C) from control assemblies used in the Superphenix (EDF-250) and Phenix and Rapsodie (CEA-380) fast neutron reactors. These pins may contain sodium residue not removed during washing of the control rods.

- ***Packages of primary- and secondary-source rods from pressurised water reactors and miscellaneous spent sealed sources from EDF (EDF-110)***

This waste family contains primary and secondary source fuel rods used in PWRs. The method of conditioning method for source rods has not yet been defined. The reference option is the placement of sheared rods inside CSD-C metal containers (or equivalent). An alternative would be to condition the rods as is in lengthy packages (approx. 4.5 m).

- ***Waste packages from the irradiated materials facility at Chinon (EDF-120)***

The EDF-120 family contains the waste stored in shafts at the Irradiated Materials Workshop (AMI) in Chinon. It mainly comes from assessment activities. It consists of a wide variety of waste types from the PWR and GCR series. The conditioning methods for this waste have not yet been determined.

- ***Activated dismantling waste (DAD) from PWR reactors (EDF-100)***

This is waste that will be produced when the PWRs are dismantled. The current scenario adopted by EDF is to place it in optimised metal containers. The facility to be used for conditioning this waste will be defined in liaison with the dismantling of the first PWR units.

1.2.3 Families of waste package generated from the operation (excluding bituminised waste) and dismantling of fuel cycle facilities

- ***Packages of cemented technological waste (CSD-C) from La Hague (COG-460 and COG-490)***

The compacting process used at La Hague for conditioning structural waste from spent fuels will also be used in the coming years to condition certain types of operating and dismantling waste from the UP2-400 plant (COG-460) and the UP2-800 and UP3 plants (COG-490) into CSD-C packages.

- ***Packages of cemented solid operations waste generated by Areva/La Hague before 1994 (COG-050)***

The COG-050 family corresponds to packages produced between 1990 and 1994 of technological waste embedded in cement in asbestos-cement containers, and not suitable for surface disposal.

- ***Packages of cemented solid operations waste generated by Areva/La Hague after 1994 (COG-030, COG-480, COG-500, COG-510 and COG-520)***

Most solid technological waste from the La Hague plant with contamination levels that make surface disposal infeasible is conditioned in fibre-reinforced concrete containers (CBF-C'2). This waste is made up of metal or organic materials. It is collected in metal canisters or drums or in polyethylene canisters, which are then immobilised inside the CBF-C'2 containers using fibre-reinforced concrete (COG-030).

Waste from the dismantling of the UP2-400 (COG-480), UP2-800 and UP3 (COG-500) plants at La Hague, the MELOX plant (COG-510) and the Cadarache fuel fabrication facility (COG-520) will be immobilised by a cementitious material inside a fibre-reinforced concrete or metal container.

- ***Waste packages from Areva/La Hague contaminated with alpha-emitters (COG-400)***

This family contains packages of solid waste contaminated mainly with plutonium during MOX fuel fabrication (MELOX plant and fuel fabrication facility at Cadarache) or fuel reprocessing (La Hague plants). It consists of miscellaneous metal waste (tools, cables, etc.) and organic waste (gloves, extraction hoses, etc.). Waste packages from operations prior to the final shutdown and dismantling of facilities at the UP2-400 plant at La Hague are also assigned to this family. The conditioning hypothesis previously applied by Areva was compacting. At ASN's request, Areva is currently researching an alternative conditioning method to direct compacting, which will be an incineration/melting/vitrification process. The corresponding package is the PIVIC package.

- ***Vitrified waste packages (CSD-B) - rinse effluent from Areva/La Hague (COG-470)***

The conditioning used for certain intermediate-level effluents produced during rinsing operations performed as part of the final shutdown of plant UP2-400 (COG-470) is vitrification and conditioning in identical containers to those used for vitrified high-level waste.

- ***Packages of dried and compacted STE2 sludge from Areva/La Hague (COG 430)***

'STE2' sludge is the precipitates immobilising the activity contained in low-level and intermediate-level secondary effluents from the La Hague plant. It is mainly from the operation of the UP2-400 plant between 1966 and 1997 and is stored in 7 silos numbered 550-10 to 550-15 and 550-17 at the former effluent treatment plant (STE2). The process currently used to condition this waste is drying prior to compacting the sludge in the form of pellets, which will then be conditioned in stainless steel drums.

- ***Packages of fine suspensions and resins from Areva/La Hague's HAO silo (COG-440)***

COG-440 contains the packages that will be produced by the conditioning of small particle-size process waste (fines from dissolution/clarification, resins and some fines from shearing) stored in the silo of the HAO (High Activity Oxide) unit. The current conditioning hypothesis applied by Areva is cementation of the waste in stainless steel drums.

- ***Packages of solid AVM operations waste in stainless steel containers from CEA/Marcoule (CEA-1110)***

Solid maintenance waste generated by the Marcoule vitrification facility (AVM) since its start-up in 1980. This waste (pieces of melting vessels, glass residues, steel tools) is placed in stainless steel containers of the same geometry as the AVM glass containers.

- ***Packages of process waste from CEA/Marcoule (CEA-1040)***

Process waste of various types and related to the operating, decommissioning, and dismantling of the UP1 plant: pool water filtration systems (ion-exchange resins, zeolites, etc.), graphite powder from fuel used in the gas-cooled reactors (GCR), and deposits removed from the vessel bottom during dismantling of the UP1 plant. At this stage, the conditioning method adopted by CEA for this waste is to embed it in a cement matrix and place it into EIP drums. These packages will be produced by 2030.

1.2.4 Families of waste packages generated from the operation (excluding bituminised waste) and dismantling of CEA research facilities

- ***Packages of sludge or evaporation concentrates embedded in a cementitious material (CEA-070, CEA-100, CEA-140, CEA-150, CEA-280, CEA-310, CEA-320, CEA-1140)***

Existing packages of this waste come from the conditioning of filtration sludge or evaporation concentrates from effluent treatment plants at the Cadarache and Fontenay-aux-Roses (CEA-070, CEA-100, CEA-140, CEA-150 and CEA-280) and Valduc (CEA-320) facilities. The sludge has been chemically treated, mixed with cement, then conditioned in non-alloy steel drums. The concentrates have been embedded in a cement-based matrix and conditioned in metal drums. Some of these packages have been placed in concrete hulls or steel containers, either permanently or not. The packages to be produced relate to co-precipitation sludge from effluent treatment on the Marcoule site, which is currently bituminised but in future will be immobilised in cement and conditioned in stainless steel drums (CEA-1140).

- ***Metal and organic waste immobilised in a cementitious material (CEA-120, CEA-290, CEA-440, CEA-480, CEA-1090)***

Packages of moderately irradiating solid waste from the operation, maintenance, remediation or dismantling of CEA facilities. This waste is conditioned in metal drums and comes from different CEA centres (Fontenay-aux-Roses, Saclay, Cadarache, Valduc, Marcoule, etc.); it consists mainly of metals, cellulose or plastics, rubber, plaster, paint and glassware.

- ***Packages of waste from the core of the CEA's Marcoule Phenix reactor (CEA-360 and CEA-370)***

Waste from the core of the Phenix reactor comprises the steel assemblies surrounding the core, a portion of the lateral neutron shielding, the core support structure (diagrid and dummy diagrid) and cobalt capsules insufficiently irradiated to be used as sources. These irradiating objects are currently still in place in the core of the Phenix reactor. This waste will be generated between 2017 and 2025, placed into Diadem storage containers (without being immobilised) then emplaced within the future Diadem facility. The conditioning method for the disposal of the waste inside the Diadem containers has yet to be defined.

- ***Vitrified packages of AVM rinse effluent from CEA/Marcoule (CEA-1120)***

Effluents produced during operations to remediate the UP1 plant as well as some effluents from other CEA sites (Valduc, Fontenay-aux-Roses, Cadarache). They are vitrified then conditioned into AVM stainless steel containers. Its low decay heat enables it to be included under the category of ILW-LL. This waste was generated between 2009 and 2012.

- ***Packages of miscellaneous predominantly metal waste to be conditioned or reconditioned (CEA-430, CEA-1151, CEA-1152, CEA-1200)***

These CEA families consist of irradiating waste that has been, is being, or will be, produced by the operation, remediation and dismantling of certain CEA facilities. Most of this waste will be placed into Diadem storage containers and stored at the future Diadem facility. The conditioning method for the disposal of the waste inside the Diadem containers has yet to be defined. The conditioning method for other types of waste remains to be defined.

- ***Packages of radium-bearing lead sulphates from the Le Bouchet plant (CEA-231, CEA-232)***

CEA's plant in Le Bouchet, which processed imported uranothorianite between 1958 and 1970 in order to extract uranium and thorium, generated radioactive residues — radium-bearing lead sulphates from decontamination of the bases of the ore extraction tower. These residues were conditioned on site in metal drums and underwent a series of reconditioning operations.

- ***Packages of metal and organic waste immobilised in a cementitious material (CEA-050, CEA-060, CEA-090, CEA-270, CEA-330, CEA-1100)***

Packages of solid waste from the operation, maintenance and dismantling of CEA facilities. They are heavily contaminated with alpha emitters and are conditioned in non-alloy steel containers. This waste is primarily made up of metal and plastic. The primary waste comes from the Cadarache centre and other CEA centres. It may or may not be compacted before being immobilised in a cementitious material in containers.

- ***Packages of waste immobilised in a cement-bitumen matrix from Cadarache (CEA-080, CEA-110, CEA-300)***

Packages of slightly irradiating solid waste from the operation, maintenance and dismantling of CEA facilities. They are conditioned in non-alloy steel containers and immobilised in a cement- and bitumen-based material. Their production ended in 1990.

- ***Packages of vitrified radioactive effluents from Pu recycling at CEA/Valduc (CEA-340)***

The reprocessing of recyclable products containing plutonium produces effluents containing americium, plutonium and uranium. These effluents are currently stored on the Valduc site. The hypothesis applied for their conditioning is vitrification at a facility to be built on the Valduc site, followed by conditioning in a standard container of the type used on the La Hague site. The thermicity of the vitrified waste produced in this way will be low, enabling it to be assigned to the ILW-LL category.

- ***Packages of spent sealed sources (CEA-450, CEA-1510)***

Spent sealed sources used for various purposes (neutron sources, sources containing natural uranium, radium, plutonium or americium) by CEA (which, as supplier, retrieved many spent sources). Some of these are already conditioned in concrete or metal containers.

- ***Packages of alpha waste from CEA/Marcoule in 200-l drums (CEA-1180)***

Solid technological waste produced by the UP1 plant and contaminated with pure alpha emitters. This waste was wrapped in a double thickness of vinyl, conditioned in 100-l or 118-l drums, then compacted into pucks. The pucks are conditioned in 200-litre carbon steel or stainless steel drums then immobilised in gravel and mortar.

- ***Packages of irradiating waste from CEA to be reconditioned (CEA-400, CEA-410, CEA-420 and CEA-460)***

Irradiating waste that is being or will be produced by the operation, remediation and dismantling of certain CEA facilities. CEA-400, CEA-410 and CEA-420 waste will be placed into Diadem storage containers then emplaced within the future Diadem facility. The conditioning method for the disposal of the waste inside the Diadem containers has yet to be defined. CEA-460 waste will be conditioned into 870-l packages.

1.2.5 Bituminised waste package families

- ***Packages of bituminised waste from Areva/La Hague (COG-020, COG-420)***

COG-020 consists of treated sludge that is embedded in bitumen at La Hague effluent treatment plant 3 (STE3). COG-420 is the bituminised fraction of the sludge from the treatment of effluent at STE2. STE2. It is stored in silo 550-14 at La Hague.

- ***Packages of bituminised waste from CEA/Marcoule produced before January 1995 (CEA-1020, CEA-1021)***

All the packages of bituminised sludge produced at the Marcoule liquid effluent treatment plant between 1966 and the introduction of "product quality monitoring" in 1995. These packages are conditioned in non-alloy steel drums. Some packages have already been retrieved and placed into EIP drums. These new packages are stored at the EIP.

- ***Packages of bituminised waste from CEA/Marcoule produced since January 1995 (CEA-1000, CEA-1010)***

All the packages of bituminised sludge produced since the introduction of 'product quality monitoring' in 1995. Some of these packages are conditioned in non-alloy steel drums (CEA-1010), and the rest (since 1996) in stainless steel drums (CEA-1000).

1.2.6 Families of waste packages generated from the operation, maintenance, and dismantling of new facilities

- ***Waste packages from the ITER reactor (ITER-010)***

ITER waste will be produced when components are replaced during operation and removed after final shutdown. This waste is characterised by its content of tritium and activation products and by the type of some of the waste.

- ***Waste packages collected by Andra (AND-000)***

Includes radium-bearing items for medical use (ORUM) (AND-050) consisting of very small metal needles and tubes that contain a few milligrams of radium each; sources from smoke detectors; sources from lightning conductors containing americium or radium; spent sealed sources collected by Andra, particularly as part of its public service role; and a few 200-l drums of silica contaminated by carbon-14 from Isotopchim. Andra is considering conditioning this waste in 870-l drums.

1.2.7 Summary of ILW-LL package families

The tables in Appendix 1 summarize the variability of the ILW-LL waste package families intended for Cigeo and their production status and their quantity.

Note: The production status is indicated in the last column:

- [T]: waste packages that are no longer in production.
- [EC]: for waste packages currently in production.
- [F]: waste packages for which production has not yet started but for which the definition of the conditioning method is already well advanced.
- [AD] for waste package families yet to be produced and for which conditioning is still at the research stage.

1.3 Type of HLW waste package

1.3.1 Type of vitrified waste package

- ***CSD-V vitrified waste packages from Areva/La Hague (COG-140, COG-200, COG-800, COG-810, COG-820, COG-830, COG-880, COG-890 and COG-900)***

These packages are standard canisters for vitrified waste (CSD-V) made from stainless steel in which solutions of fission products and minor actinides, calcined and incorporated into a glass matrix, are conditioned in the R7 and T7 vitrification facilities at La Hague. The fission product solutions come from the reprocessing of UOX fuels (COG-140 and COG-800 for fuels with higher burnup rates), from the reprocessing of spent fuels from the CEA and from the Brennilis EL4 reactor (COG-880 for CEA/Civil, COG-890 for CEA/DAM and COG-900 for EL4), from the reprocessing of spent MOX fuels mixed with spent UOX and ERU fuels (COG-200), and from the reprocessing of spent fuels from the Phenix and Superphenix fast neutron reactors mixed with UOX fuels (COG-830).

Vitrified waste packages are also produced when the vitrification furnace is purged (COG-810) and from calcines from calciner cleaning operations (COG-820).

- ***Packages of vitrified molybdenum fission product solutions from La Hague (COG-150)***

These packages come from the vitrification of fission product molybdenum solutions using a similar process to the one used today for producing vitrified waste packages, but using a "cold crucible" technology combined with a new glass formulation. These solutions, stored on the La Hague site, come from the reprocessing of spent fuels known as "UMo" (consisting of a uranium-molybdenum alloy) used in gas-cooled (graphite-moderated) reactors (GCRs) now shut down.

- ***Vitrified waste packages from the Marcoule vitrification facility (CEA-1070 and CEA-1080)***

These packages come from vitrification campaigns at the Marcoule vitrification facility (AVM), which began in 1978. Production in compliance with a quality assurance specification began in March 1995 and corresponds to the CEA-1070 family. Production prior to 1995 corresponds to the CEA-1080 family.

- ***PIVER vitrified waste packages from CEA/Marcoule (CEA-200 and CEA-1190)***

The development and refinement of the waste vitrification process were undertaken by the CEA at several facilities in the Marcoule pilot facility (APM) from the early 1960s. These studies led to the construction of the first industrial pilot facility for the vitrification of spent fuel dissolution solutions (PIVER).

The fission product solutions vitrified at this facility came partly from the reprocessing of Sicral-type spent fuels (Si Cr Al: a uranium, silicon, chromium and aluminium alloy) used in GCRs (gas-cooled reactors), and partly from the reprocessing of UO2-based fuels irradiated in the Phenix fast neutron reactor. These packages (CEA-200) were produced between 1969 and 1973 in the case of the Sicral vitrified waste packages (94% of the total) and between 1979 and 1980 in the case of the Phenix vitrified waste packages.

Research led in parallel to the manufacture of vitrified waste samples conditioned in stainless steel containers of different geometries, which are now stored in building 213 of the APM (CEA-1190).

- ***Packages of vitrified Atalante waste from CEA/Marcoule (CEA-350)***

Research conducted in Atalante on UOX and MOX fuels generates radioactive effluents, which have to be vitrified in an Atalante shielded process line. The conditioning process envisaged by the CEA consists of vitrification of the waste in metal pots, grouping and immobilisation of the pots in a basket with glass frit, then loading into a stainless steel AVM-type container. Production of these packages is expected to begin by 2030.

1.3.2 Other HLW (spent sealed sources, technological waste, etc.)

- ***Packages of technological waste from the Areva/La Hague vitrification facilities (COG-850)***

In the first few years of operation of the R7 vitrification facility in La Hague, technological waste from the facility's operation was conditioned in standard stainless steel canisters of identical external geometry to that of the vitrified waste packages from La Hague. The same conditioning is envisaged for baskets of technological waste such as pieces of glass and cut up equipment from the R7 and T7 facilities.

- ***Packages of strontium titanate capsules from Areva/La Hague (COG-870)***

The Elan IIB facility, located in La Hague, was a pilot for producing sealed sources of caesium-137 and strontium-90. The strontium arrived at the Elan IIB facility conditioned in metal canisters (capsules) and was separated, compacted and conditioned in a double-layered container. This facility, operated by the CEA, went into operation in 1970. Production was shut down from 1973. Fifteen strontium titanate capsules are currently stored at La Hague. The process envisaged at present for the conditioning of these capsules is to immobilise them in a standard stainless steel canister. The choice of immobilisation matrix is currently being studied.

- ***Waste packages from ELAN IIB elution columns conditioned into standard containers from Areva/La Hague (COG-860)***

The Elan IIB facility, located in La Hague, was a pilot for producing sealed sources of caesium-137 and strontium-90. The caesium was transported from CEA/Marcoule in elution columns on a mineral exchanger then eluted, concentrated and calcined. The caesium oxide powder was then sintered and conditioned in a double-layered container. Four elution columns are currently stored at La Hague. The conditioning process for the mineral exchanger of these elution columns has not been decided. At this stage, conditioning in a standard stainless steel canister is the chosen solution.

- ***Packages of spent sealed sources (caesium-137, strontium-90, plutonium-238) from CEA (CEA-1500)***

These are highly radioactive sources containing caesium and strontium, some of which come from isotope generators, along with a batch of sources from cardiac pacemakers (plutonium-238). These sources will be conditioned in a package of identical external geometry to the AVM glass package.

1.3.3 Summary of HLW package families

The table in Appendix 2 summarizes the entire range of HLW package intended for Cigeo as well as their respective quantities.

Note: Just as for the ILW-LL packages, the production status is indicated in the last column:

- [T]: waste packages that are no longer in production.
- [EC]: for waste packages currently in production.
- [F]: waste packages for which production has not yet started but for which the definition of the conditioning method is already well advanced.
- [AD] for waste package families yet to be produced and for which conditioning is still at the research stage.

1.4 ILW-LL disposal packages

When a primary package is supplemented by a disposal container, the combined set makes up a disposal package that is transferred for emplacement into the underground facility. An ILW-LL disposal package thus consists of:

- A container comprising the following two precast items:
  - ✓ A container body with internal partitions that form housings fitted to the shape of the primary packages.
  - ✓ A lid.
- One or more primary packages (optional, in the case of primary packages without handling slots) and possibly one or more optional spacers.

The possibility of dispose of some ILW-LL primary packages within Cigeo without adding a disposal container is being considered. In such case, the primary package will be considered as a disposal package.

Three disposal package solutions are being considered for the disposal of ILW-LL packages with Cigeo:

- Solution 1 (applies to most waste package families):

Primary packages intended for Cigeo are placed within a "reference" disposal container upon its arrival in the facility or before being shipped by its generator.

- Solution 2 (applies to some waste package families):

Primary packages intended for Cigeo are placed within a 'reinforced with respect to containment' disposal container that, in addition to the functions of the "reference" container (see solution 1), ensures a containment function to overcome uncertainty about maintaining containment throughout the reversibility of the repository once the primary package is emplaced within a cell. This disposal container ensures containment in the event of premature degradation of primary package within the cell. Grouting of the disposal package is currently adopted as the basic technical solution for this "reinforced" package. This particularly relates to some families of waste already generated.

- Solution 3 (for some families referred to as "eligible for direct disposal"):

Primary packages intended for Cigeo are not placed inside disposal containers but directly into the disposal cell. In this case, the primary packages must meet the assigned functions of a primary package that would be placed within a "reference" disposal container. Their radiological, mechanical, and physical and chemical characteristics must be compatible with the facility's design (containment class of the ILW-LL disposal cell in particular) without the protection afforded by any kind of disposal container. This relates to C1PG, CSD-C, and CBFC’2 waste families. This list also includes package families for which the conditioning is still at the research stage.

In the case of the waste families referred to as "eligible for direct disposal", detailed engineering design studies will be conducted by looking at solution 1 and solution 3, respectively. Based on the demonstration elements provided, the safety analysis report will specify the chosen solution in the construction licence application.

As regards solution 2, tests and simulations will be carried out to verify the relevance of the grouting at the detailed engineering design phase. Depending of the results obtained, it may be ultimately decided to not adopt this solution.

1.4.1 Models of ILW-LL disposal package (primary package(s) in a disposal container)

Given the vast number and diversity of waste package families that will be emplaced within Cigeo, reducing the categories of disposal package will make handling operations as easy as possible and facilitate the possibility of automation of the disposal process. The entire range of ILW-LL package families will thus be combined into a limited number of containers.

The figure on the following page summarises the disposal containers and associated families of waste package based on their geometry and weight. As for waste package families for which the conditioning method has not yet been defined, the geometry and weight of these packages will have to comply with the specification plan for their intended container and the associated weight.

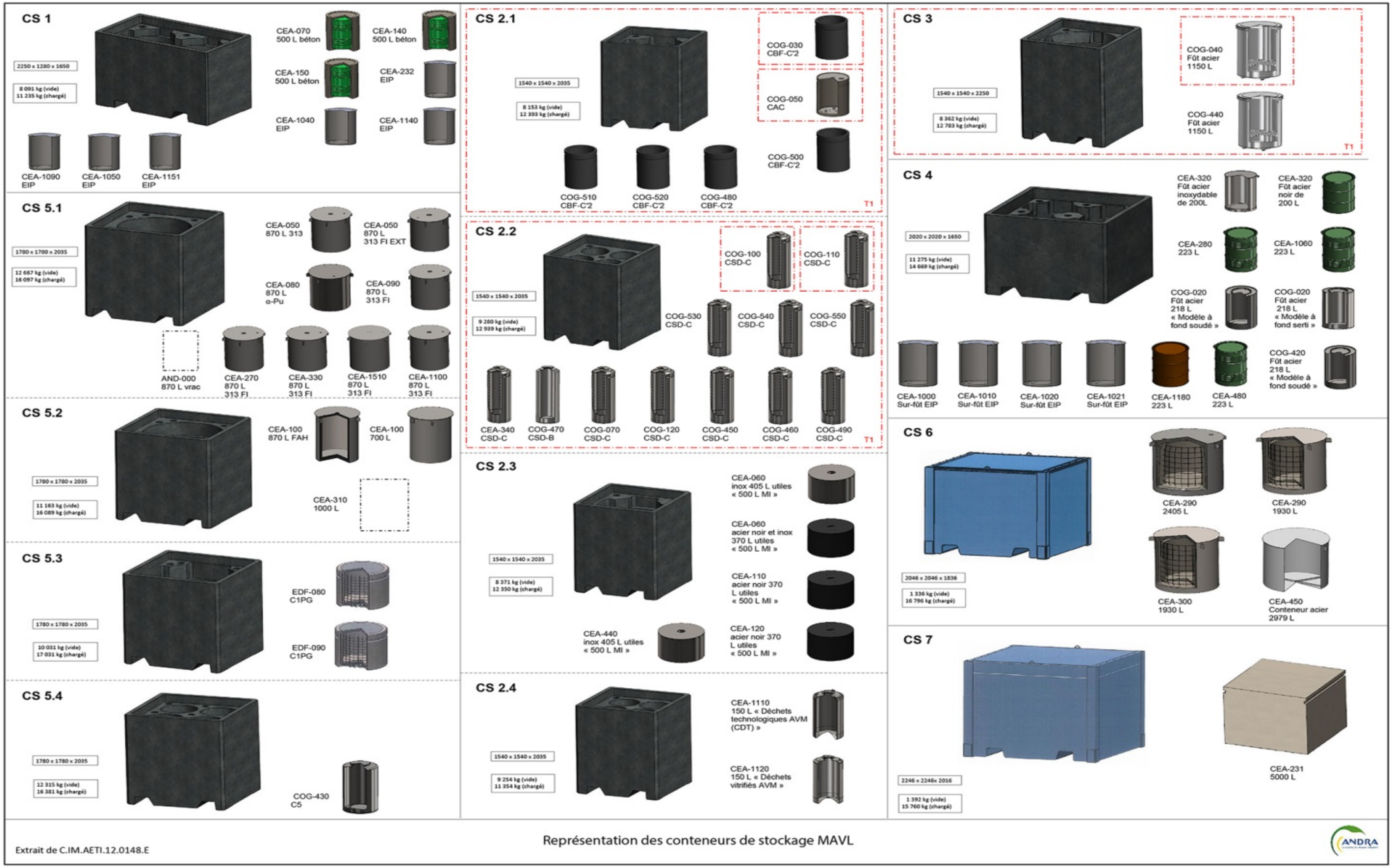

Figure 1.4-1 Current ILW-LL disposal package models

1.4.2 Functions of the ILW-LL disposal package

The functions of disposal package are summarised in the table below, with distinctions made between primary packages and disposal containers.

Table 1.4-1 List of the functions of ILW-LL disposal packages showing the differences between primary packages and disposal containers

	Disposal package solutions 1 and 2 are made up of one or more primary package and a disposal container.		**Solution 3 consists of a primary package disposed of directly without any containerisation**	**Criterion for the CP associated with the function**
	Primary package (CP) functions	**Disposal container (CtS) functions**	**Functions (combining those of the CP and the CtS)**	
Operation under normal conditions	Enable handling during surface operations involving primary packages	Enable handling of disposal packages during disposal operations and, if necessary, retrieval operations	Enable handling of packages during surface operations, disposal operations and, if necessary, retrieval operations	Geometry and weight
	Limit surface contamination to a level compatible with the facility's design		Limit surface contamination to a level compatible with the facility's design	Levels of alpha and beta-gamma contamination
	Contain non-gaseous radioactive substances at a level compatible with the facility's design (first containment barrier)	Solution 1: N/A Solution 2: Contain non-gaseous radioactive substances at a level compatible with the ILW-LL disposal cell's design and throughout the facility's service life	Contain non-gaseous radioactive substances at a level compatible with the facility's design and throughout its service life	Physical and chemical characteristics Presence of powders
	Ensure criticality hazard control by limiting the weight of the fissile material in each package and via the package geometry	Ensure criticality hazard control by limiting the weight of the fissile material in each package and via the disposal container geometry	Ensure criticality hazard control by limiting the weight of the fissile material in each package and via the package geometry	Weight of the fissile material Package geometry

	Disposal package solutions 1 and 2 are made up of one or more primary package and a disposal container.		**Solution 3 consists of a primary package disposed of directly without any containerisation**	**Criterion for the CP associated with the function**
	Primary package (CP) functions	**Disposal container (CtS) functions**	**Functions (combining those of the CP and the CtS)**	
	Limit the generation of radiolysis gases (H_2) to a level compatible with the facility's design and operation	Enable the removal of gases emitted by primary package to prevent the risk of internal explosion	Limit the generation of radiolysis gases to a level compatible with the facility's design and operation	H_2 degassing rate
	Limit decay heat to a level compatible with the design of the facility and disposal container		Limit decay heat to a level compatible with the facility's design	Decay heat
	Limit the dose rate to a level compatible with the facility's design and operation		Limit the dose rate to a level compatible with the facility's design and operation	Gamma and neutron dose rate
	Enable identification of primary packages	Enable identification of disposal packages	Enable identification of disposal packages	Type of labelling
		Enable disposal packages to be stacked within cells	Enable packages to be stacked within cells	Stacking strength (solution 3)
Operation — Incident conditions, accidental fire and accidental drop/collision	Limit the dispersion of particles and aerosols to a level compatible with the facility's design	Protect primary packages from thermal and mechanical stresses Mitigate the dispersion of particles and aerosols where appropriate	Limit the dispersion of particles and aerosols to a level compatible with the facility's design	Level of resistance to fire, drops and collisions
	Maintain criticality hazard control by limiting the weight	Ensure criticality hazard control by limiting deformations to disposal containers	Maintain criticality hazard control by limiting the weight	Weight of the fissile material

	Disposal package solutions 1 and 2 are made up of one or more primary package and a disposal container.		**Solution 3 consists of a primary package disposed of directly without any containerisation**	**Criterion for the CP associated with the function**
	Primary package (CP) functions	**Disposal container (CtS) functions**	**Functions (combining those of the CP and the CtS)**	
		Maintain the handling function	Maintain the handling function	Level of resistance to fire, drops and collisions (solution 3)

1.4.3 Design options for the ILW-LL disposal container

Parallelepipedal concrete containers will be used for most waste packages (CS1 to CS5 disposal containers), while steel containers will be used for a few waste packages (CS6 and CS7 disposal containers).

The technical solution selected by Andra for the concrete containers consists of precast reinforced elements made up of a body and a lid. The lid will be secured by screws on most of the primary packages. One solution under consideration is to grout the lids on some primary packages.

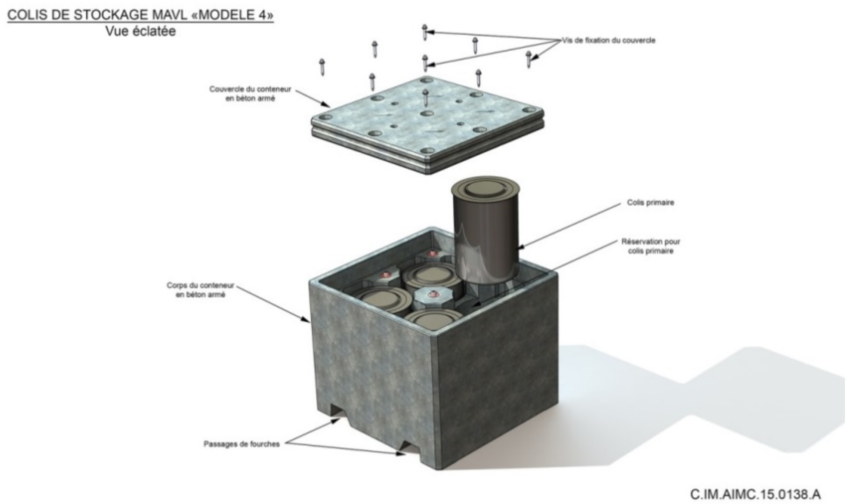

Figure 1.4-2 CS4 ILW-LL disposal container with lid secured by screws

The precast containers have slots to allow them to be lifted and moved by a forklift truck. The dimensions of these slots are the same on all the container models to promote the standardisation of handling equipment and thus automation. This method of precast conditioning makes it possible to limit the generation of operations effluent at Cigeo. The maximum weight of the disposal packages is 17 tonnes.

The technical solution being considered for identifying the disposal packages is to mark all four sides of the packages with paint. Furthermore, all ILW-LL primary packages emplaced within Cigeo will be identified to ensure traceability (control of package data and control of the locations of packages within the facility). Marking methods involving the making of cuts in the concrete are excluded.

Containment is ensured by primary packages. For some families of package already generated and for which containment throughout Cigeo's service life is not guaranteed, a cementitious grout may be injected into the gap remaining between the container body and the lid to prevent the dispersion of radioactive substances.

The disposal containers promote radiolytic off-gassing from the primary packages preferably via the gap between the lid and the container body. Simulations and tests conducted on the solutions being investigated show that the pouring of a cementitious grout or a cast lid does not prevent this off-gassing because the formulation of the grout or concrete also makes the diffusion of gas possible. The forklift slots promote the circulation of air into the cells and thus the removal of radiolysis gases.

The stacking strength is not a critical design parameter for the grade of concrete to be used or the thickness of the container. Control of the location of the vertical load distribution of one container onto another have been specifically studied and the areas of contact between containers have been well identified. Likewise, a lid recess thickness in relation to the support surface of the top of the container body (approx. 15 mm) has been adopted. The specific areas of contact are shown in the figure below.

Figure 1.4-3 Pictures of the bottoms of the containers during casting and on a full-scale prototype.

The selected container formulation makes it possible for the containers to withstand the stresses associated with their handling during normal operation (transfer, emplacement, retrieval).

<u>Drop resistance.</u> The concrete ILW-LL disposal containers were designed based on prevailing standards (Eurocode 2 – EN 1992-1-1). The following minimum dimensions were established using numerical simulations and tests conducted on full-scale prototypes (see Figure 1.4-4 and Figure 1.4-5 Figure 1.2-1):

- Lid thickness: 160 mm.
- Minimum distance between the closure systems and the edge of the lid: 110 mm.
- Recess of the lid relative to the top surface of the container body: 15 mm
- Thickness of the side walls: 160 mm.
- Thickness of the bottom (excluding the handling slots): 160 mm.

The inserts built into the lid and container body, specifically designed to form a shear-resistant system in the event of drops, demonstrated their effectiveness during the full-scale tests. The maximum drop height for the mechanical design of all the disposal container models is taken to be 2.3 m without turnover (flat drop onto bottom, drop onto edge and corner).

Figure 1.4-4 Demonstration of a drop test for a CS4 container

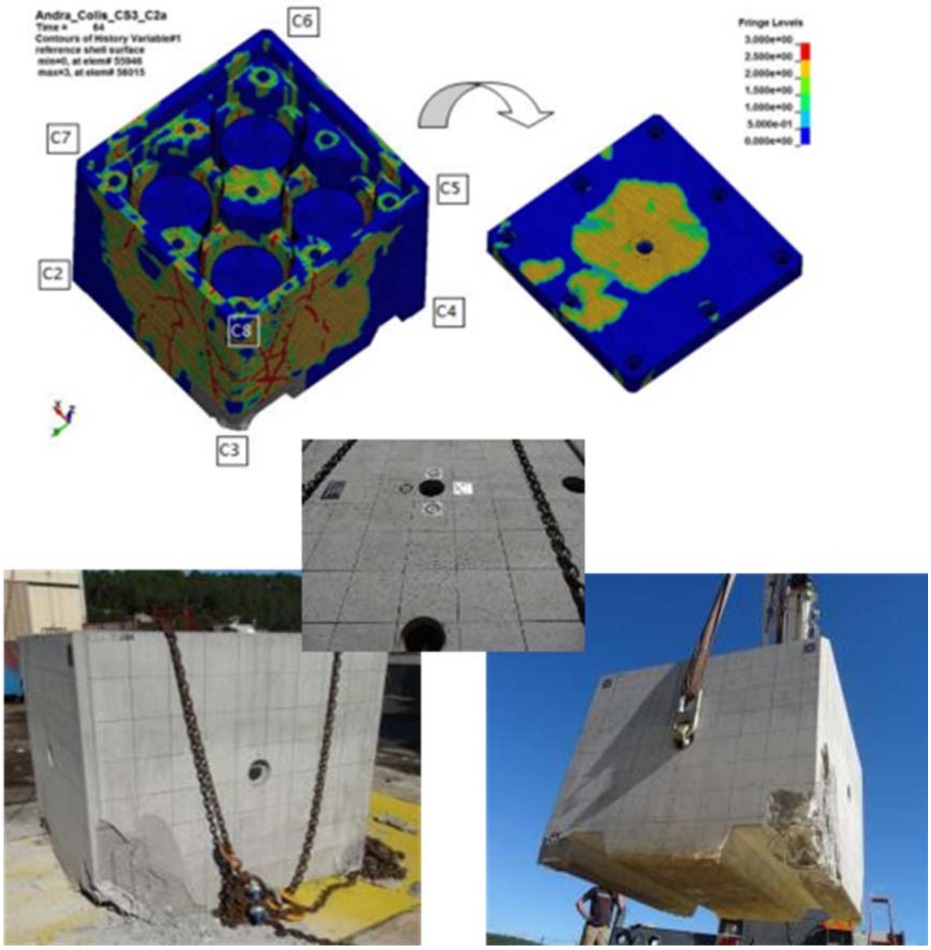

Figure 1.4-5 A CS4 container before and after being dropped onto one of its corners from a height of 2.3 m (results of numerical simulations and results with full-scale prototypes)

<u>Fire resistance.</u> The concrete formulation was selected to ensure that handling of the packages will remain possible following a potential fire. At this stage, the reference fire used to design the concrete disposal containers is a one-hour ISO 834 fire. The formulation and thickness of the concrete walls for containers intended to hold bituminised waste packages (20 cm at this stage) make it possible to ensure thermal protection (compliance with the criterion of the surface temperature of the primary package in the event of a fire). Polypropylene fibres are added to the formulation of these containers to improve the resistance of the concrete to bursting due to heat. This principle has been confirmed by tests (28) and (29).

CS4 container — Sealed and grouted container, before fire test

CS4 container — After fire test (one-hour ISO 834 fire)

Figure 1.4-6 Sealed, grouted and instrumented CS4 container for one-hour ISO 834 fire test. Condition of the full-scale prototype before and after the test.

Package durability. Once emplaced within the cells, the durability of the disposal containers means that the concrete must withstand all forms of internal (from the waste) and external (from the environment) chemical attack. Such durability is obtained by using a material that is effective — in terms of choice of component materials and formulation — and careful implementation of the concrete surrounding the reinforcements. Thus, the various studies conducted by Andra on the construction of the concrete ILW-LL containers resulted in the definition of concrete formulations within the high-performance concrete (HPC) range. The raw materials are selected, near Cigeo's future site where possible, specifically on the basis of recommendations from the concrete industry and on operating experience feedback acquired by Andra on the behaviour of cementitious materials used in the environmental conditions expected to be present within Cigeo.

For example, the choice was made to use a sulphate-resisting (PM-ES) composite cement (containing fly ash and slag) and non-alkali-silica reactive aggregate. The composition of these cements aims also to improve their long-term strength. Indeed, a high cement content and a low water content make it possible to limit the number of voids inside the cement and reduce its brittleness.

At this stage, a nominal embedment depth[24] of 40 mm has been defined to guard against corrosion of the reinforcements. The quality of the material will also make it possible to slow down ingress of harsh chemicals. The environmental exposure classes taken into account are XA2 for risks of chemical attack and XC1 for risks of corrosion induced by carbonation.

1.4.4 Fabrication of the ILW-LL disposal containers

Tests have been conducted to develop the formulations (Figure 1.4-7 and Figure 1.4-8). They comprise the development of prototypes used to verify the industrial feasibility of the selected technical solution.

Figure 1.4-7 Characterisation of the spread of the reference formulation with polypropylene fibres

[24] According to Eurocode, the nominal embedment depth is the sum of the minimum embedment depth depending on the desired durability and a margin for the related to the construction tolerances.

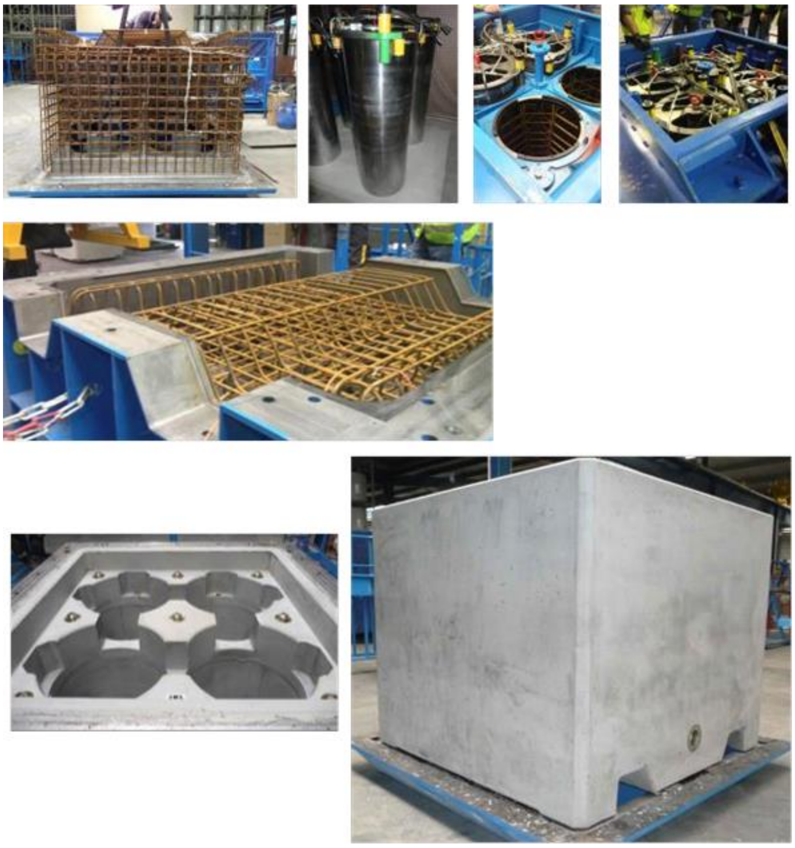

Figure 1.4-8 The steps in the fabrication of the CS3, CS2 and CS4 prototypes

After its fabrication, each reinforced concrete container will be left to cure at the plant for several months to allow the cement hydration reactions to finish and the concrete to achieve a sufficient level of mechanical strength.

Quality control inspections will be carried out at the plant before shipment:

- Quality controls of the raw materials used.
- Measures of the mechanical strength and shrinkage of concrete samples.
- Geometry and weight inspections.
- Checks of the facing quality and of acceptance criteria for pinholes and surface imperfections.
- Visual checks for chips and spall.

In addition the checks on the primary packages, inspections will be performed within Cigeo during containerisation and on the disposal packages themselves.

1.5 HLW disposal packages

HLW disposal packages are made up of the following components:

- One or more primary packages.
- A container body made of non-alloy forged steel and comprising a shell with a welded bottom.
- A lid.
- Four chemically inert ceramic pads avoiding direct steel-on-steel contact between the disposal package and the sleeve lining the disposal cells. These pads facilitate the sliding of the disposal packages during their emplacement and possible retrieval (see Chapter (8)
- Four pad attachment systems.

The containers are designed such that they ensure the functions required during emplacement (described in this section) and retrieval of the packages (see the Retrievability Options File [DOREC]) as well as during post-closure containment (see the DOS-AF).

1.5.1 HLW disposal package models

As with the families of ILW-LL package, the models of disposal package are designed according to the families of waste package and, specifically, the geometry of the primary packages. Primary packages of vitrified HLW are cylindrical containers that are relatively identical in terms of their geometry and radioactivity. The disposal containers are cylindrical.

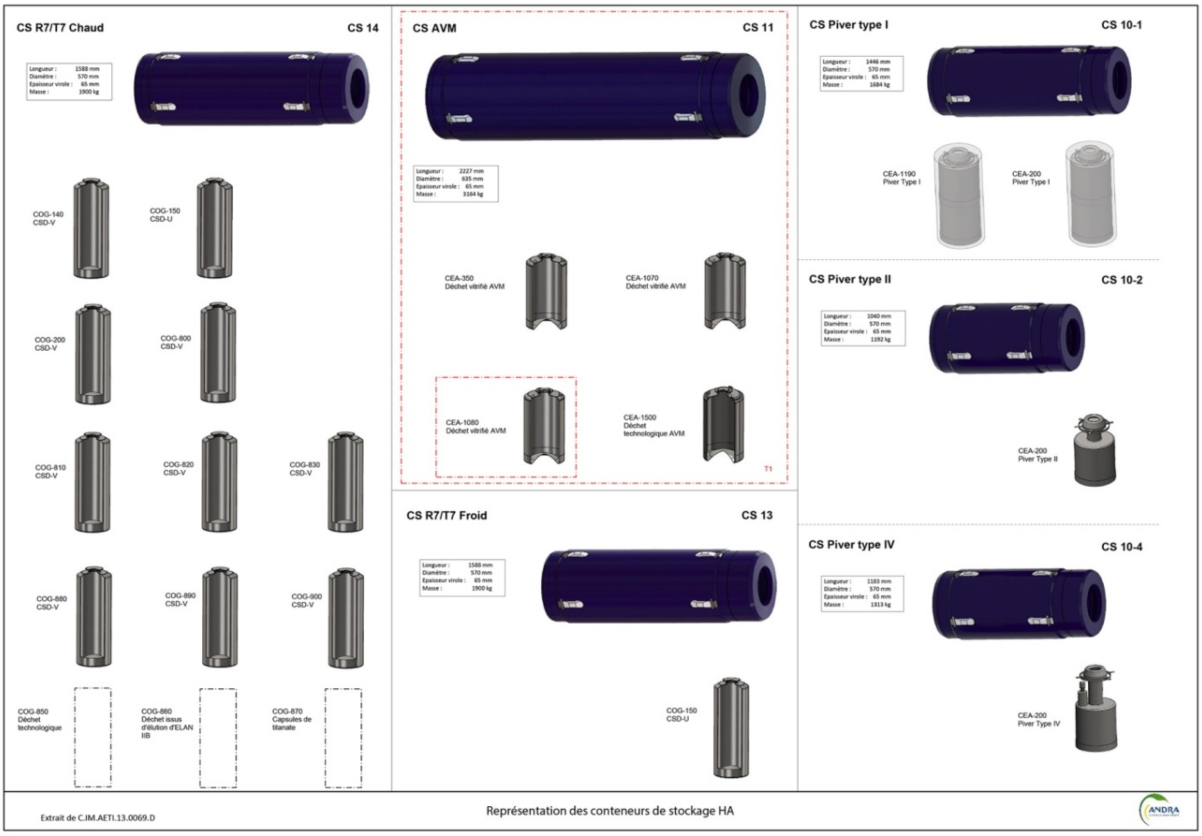

Figure 1.5-1 Current HLW disposal package models

In general, the disposal containers are designed to contain one or two primary packages. For some shorter primary package, the possibility of placing three packages is also studied

1.5.2 Function of the HLW disposal package

The functions of HLW disposal package are summarised in the table below, with distinctions made between functions assigned to primary packages and disposal containers.

Table 1.5-1 List of the functions of HLW disposal packages showing assignment to primary packages or disposal containers

	Primary package functions	**Disposal container functions**	**Criterion for the CP associated with the function**
Operation under normal conditions	Enable handling during surface operations involving primary packages	Enable handling of disposal packages during disposal operations and, if necessary, retrieval operations	Geometry and weight
	Limit surface contamination to a level compatible with the facility's design		Level of alpha and beta-gamma contamination
	Contain radioactive substances at a level compatible with the design of the facility (2nd containment barrier)	Contain radioactive substances at a level compatible with the facility's design (2nd containment barrier)	Physical and chemical characteristics
	Maintain criticality hazard control by limiting the weight of the fissile material and the geometry	Maintain criticality hazard control by limiting the weight of the fissile material and the geometry[25]	Weight of the fissile material Geometry
	Limit decay heat to a level compatible with the design of the facility and disposal container		Decay heat
	Limit the dose rate to a level compatible with the facility's design and operation	Limit the dose rate to a level compatible with the facility's design and operation	Dose rate
	Ensure gas tightness	Ensure gas tightness	Leakage level
		Protect the glass from rising temperatures during the	N/A

[25] If a HLW disposal container contains several HLW primary packages

	Primary package functions	Disposal container functions	Criterion for the CP associated with the function
		composition of the disposal package (welding and stress relief)	
		Protect primary packages from stresses within HLW cells	N/A
	Enable identification of primary packages	Enable identification of disposal packages	Type of labelling
Operation in incident conditions, accidental fire and accidental impact (drop/collision)	Limit the dispersion of radioactive substances to a level compatible with the facility's design	Limit the dispersion of radioactive substances to a level compatible with the facility's design in the event of loss of the first containment barrier (primary packages)	Level of resistance to fire and impacts (drops and collisions)
		Maintain the handling function	N/A
	Maintain criticality hazard control by limiting the weight	Maintain criticality hazard control by limiting deformations to disposal containers	Weight of the fissile material

1.5.3 Design options for the HLW disposal container

The container body consists of a cylindrical shell made of non-alloy steel with an effective thickness of between 65 and 53 mm[26], a welded bottom having a thickness suited to that of the shell, and a lid made from the same grade of forged steel in order in particular to meet the post-closure safety requirements outlined in Chapter (5).

Changes in the properties of the materials used in the design of the disposal containers are foreseeable during the period corresponding to the thermal phase. The choice of materials and the design of the container assume that general corrosion is the predominant corrosion mechanism. To ensure that the containers withstand chemical attack, Andra has selected, as a reference solution, a grade of high-ductility forged steel (such as P285NH) and is seeking an inclusion content (in particular a limitation in the phosphorus oxygen content and a favourable metallurgical structure). Reducing the impurity and inclusion content will limit the amount of anodic corrosion. The fine and homogeneous ferrite-pearlite structure is particularly strong and virtually immune to localised corrosion and stress corrosion[27].

[26] These thicknesses may be optimised between now and the filing of the construction licence application.
[27] It is considered that, throughout Cigeo's service life, corrosion phenomena will lead to corrosion of no more than a few millimetres in thickness.

As an example, Figure 1.5-2 shows a disposal package for primary packages of vitrified waste generated by the Marcoule vitrification facility (AVM).

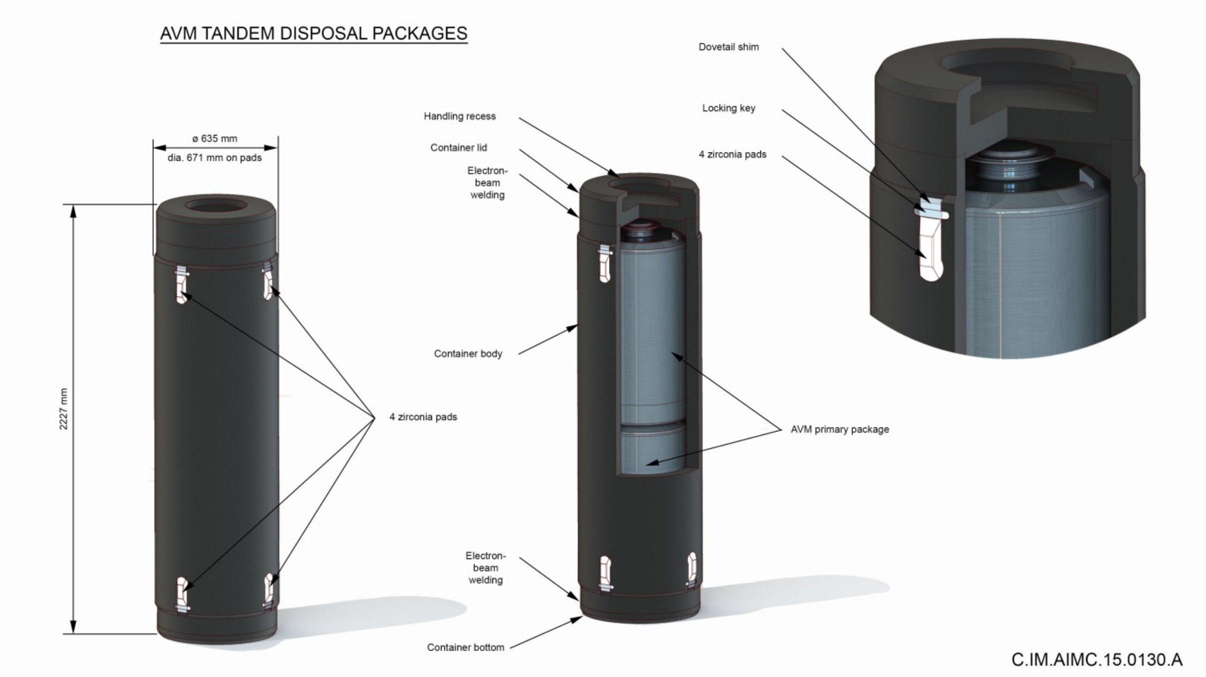

Figure 1.5-2 A tandem disposal package for AVM vitrified waste

Protection from other stresses (thermal, mechanical, etc.) during normal operation and in accident situations (drops/fire) is extensively provided by the container's robustness, which is conferred by its thickness. They are not liable to significantly alter it during Cigeo's service life.

A gripping groove machined into the disposal container lid (see Figure 1.5-3), allows handling, emplacement and possible retrieval of disposal packages during a minimum period of 100 years (8).

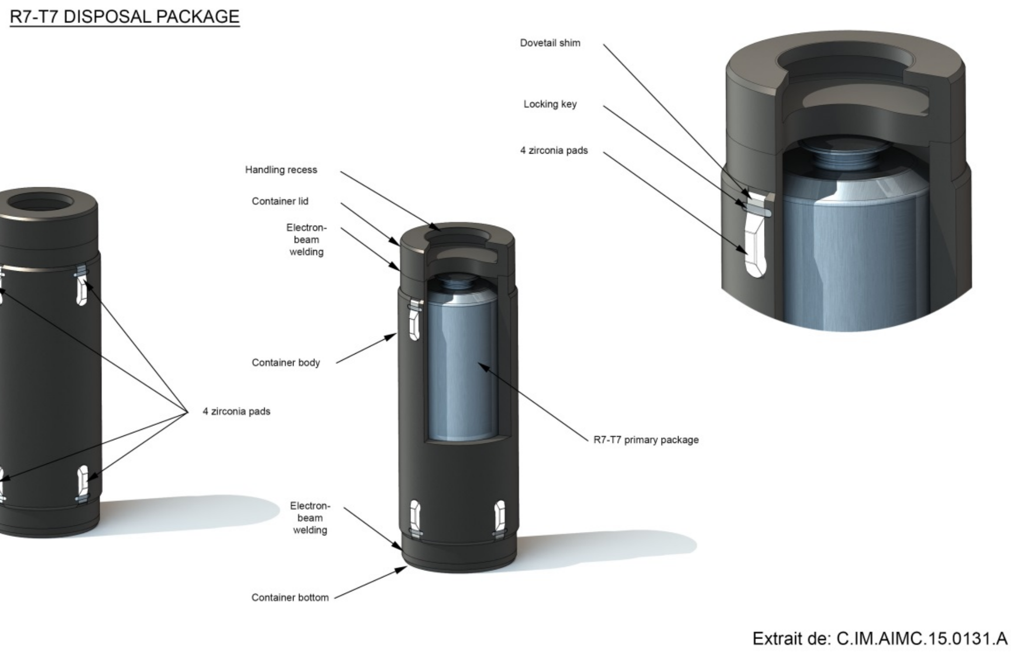

Figure 1.5-3 R7-T7 disposal package with, at top right, a detailed view of its gripping groove.

Figure 1.5-4 Etched marking on a ceramic pad.

The material of the pads has been selected for its inertness that prevents the disposal packages from sticking to the sleeve due to corrosion. The hardness (approx. 0.8 µm) and coefficient of friction (between 0.2 and 0.6) of the zirconia pads facilitates emplacement and retrieval of the disposal packages. The pads are immobilised in a dovetail groove and retained by a key welded to a dovetail shim. Each dovetail groove is machined into the container shell.

The <u>key and shim</u> are made of the same grade of steel as the disposal container. The key locks the pad against translation. The welding of the shim onto the key attaches the assembly onto the disposal package, thus ensuring that the pad is retained in place during handling of the disposal package.

The marking function is provided by the ceramic pad (see Figure 1.5-4) which, by nature, is immune to corrosion (unlike the steel components of the disposal container). Etching of the pad has been adopted as the reference technical solution. Nevertheless, it may be supplemented by paint, which is more easily recognisable by automated means during surface conditioning operations. Furthermore, all HLW primary packages emplaced within Cigeo will be identified to ensure traceability (control of package data and control of the locations of packages within the facility).

During operation, HLW disposal packages must be able to withstand static and dynamic stresses. This requirement relates to both the handling groove and the mechanical strength of the pads in their recesses:

- The residual depth of the handling groove shall be sufficient to withstand lifting and pulling stresses exerted on the disposal packages.
- The residual thickness of the ceramic pads in the dovetail grooves shall be sufficient to retain them in place.

This groove is designed to withstand every type of stress that will be encountered during the use of the disposal packages, from their conditioning to their possible retrieval. The disposal packages will be handled either vertically or horizontally using this gripping groove located in the top portion of the lid.

The strength of the shell and gripping groove of the disposal container has been verified. The analyses covered in particular the mechanical stresses calculated for the various stresses according to the French Pressure Vessel Construction Code (CODAP) and the rules recommended by the European Materials Handling Federation (FEM). The use of this code and these qualified rules improves the design confidence level.

The top surface of the lid is convex to limit the contact surface between each disposal package in the cells. This measure reduces the risk of disposal packages sticking together.

Low-carbon non-alloy steel has been chosen for the predictability of its corrosion kinetics (specifically to meet post-closure requirements). Such predictability is made possible by the codified and standardised nature of the fabrication and inspection techniques of the disposal containers. These standards define the mechanical, dimensional, and metallurgical properties of the disposal containers. They guarantee that the means and methods used to build the disposal containers are reproducible.

Drop tests conducted using a mock-up representative of a tandem AVM package dropped from a height of 5 m onto a non-deformable target and from a height of 1 m onto a punch showed the helium tightness remained unaltered after each drop (Figure 1.5-5).

Figure 1.5-5 Drop tests and helium leak tests.

The corrosion tests under way in media representative of the service life of the facility are intended to demonstrate that:

- General corrosion is the predominant corrosion mechanism.
- The mean corrosion rate is approx. 10 microns per year.
- The selected steel grade is not subject to stress corrosion and localised corrosion phenomena.
- Radiation below 20 Gy/h has no effect on the corrosion of steel.

Initial assessments of the post-buckling behaviour of the sleeve show that the body of the disposal container remains within its elastic range (P285NH steel was considered) for between one hundred and several hundred years following contact with the sleeve (assessed at 500 years).

1.5.4 Fabrication of HLW disposal packages

The adopted method of fabrication is based on codified, standardised, and controllable procurement, dimensioning and construction procedures that offer the best technique available. Low-carbon non-alloy steel has been chosen for the predictability of its corrosion kinetics. The reliability of this predictability is enhanced by the codified and standardised nature of the fabrication and inspection techniques of the containers. These standards define the mechanical, dimensional, and metallurgical properties of the containers. They guarantee that the properties of the package components are reproducible and permanent. Furthermore, after forging, the container components are subjected to normalising heat treatment to reduce residual stresses and refine the grain structure.

The bottom and the lid are welded onto the container shell by vacuum electron beam welding. This method avoids the need supply hydrogen to the molten metal of the weld zone, thus preventing weakening by hydrogen. Full-penetration welds are made using a circular motion. The intensity of the residual stress in the container (body and lid) is limited to as low as possible by stress-relief post-weld heat treatment. Tests conducted by Andra show that it is possible to reduce the residual tensile stresses to approx. 1/3 the elastic limit of the base metal. After stress relief, the hardnesses at every part of the welded joint (HAZ, MM) does not exceed the recommended limit of 250 HV (NACE) to improve resistance to hydrogen porosity. The inclusion content of the steel, in particular the reduced sulphur and phosphorus content, promotes good-quality welds.

Tests have been conducted to verify the feasibility of the proposed technical solution (see figure below).

Figure 1.5-6 Tests conducted on HLW containers.

The bottom is factory-welded onto the shell. The lid is welded onto the shell in Cigeo (after the HLW primary packages are emplaced).

Tests will be conducted both in the factory and in Cigeo to reduce the risk of fabrication defects and detect potential defects.

The following inspections will be conducted on all welded parts to ensure their conformity:

- Visual inspection of all individual steel forgings.
- Dimensional inspection after final machining.
- Ultrasonic testing (UT) of total weld volumes.

The following inspections will be conducted on welded parts in the factory and in Cigeo:

- UT to detect potential defects such as lack of fusion, cracks, and internal voids.
- Creep wave or eddy current inspection to detect potential surface defects.

Inspections will also be conducted on the ceramic pads to verify their geometry and material and mechanical properties.

1.6 Characteristics of the packages selected for the design and safety studies — Operating range

The waste will be conditioned by the waste generator. The "primary package" makes up the finished product.

Knowledge provided by waste generators on the primary waste packages makes up the input data essential to the design and safety studies for Cigeo. This input data encompass information describing the source of the waste (whether conditioned or not), the conditioning methods used, the physical and chemical properties and characteristics of the packages, and changes to and the behaviour of the packages during Cigeo's service life and after its closure.

Andra possesses a fixed reference set that is shared within the agency and knowledge on current and future waste and primary waste packages.

One of the specific features of the waste packages intended for Cigeo is the coexistence at this stage of four different levels of advancement in the production of waste packages. These levels may continue after the construction licence application:

- Waste packages that have already been generated[28] and which must be accommodated for by the design of the repository.
- Waste packages that are currently being generated and for which a conditioning method and a package production specification have been defined.
- Waste packages that have not yet been generated but for which the definition of the conditioning method is already well advanced.
- Waste packages that have not yet been generated and for which the definition of the conditioning method is still at the research stage.

All the families of waste package intended for Cigeo and belonging to these categories are listed.

Cigeo's design is based on knowledge provided by waste generators about the safety functions to be ensured for the primary packages under each of the facility's operating conditions as well as the risks and uncertainties following its final closure.

The adopted principle is that of basing Cigeo's design on the characteristics, known by Andra, of the type of waste already generated and currently being generated and for which the method of conditioning is already known.

The package acceptance specifications are established in accordance with this design.

Waste conditioning methods that are still in the research stage shall be defined such that the packages meet Cigeo's future acceptance specifications. These specifications will be drawn up as part of the construction licence application.

The design characteristics make it possible to define Cigeo's operating range.

[28] According to a waste-generation specification for some.

1.6.1 Approach

Knowledge on the primary packages makes up the input data essential to the design and safety demonstration of Cigeo. The use of this knowledge is part of an iterative approach shown in the flow chart below.

Using all the knowledge in its possession, Andra establishes a knowledge base that is applied according to the purpose: design studies (design of structures, components, equipment), performance assessments, or safety assessment during operation or after closure.

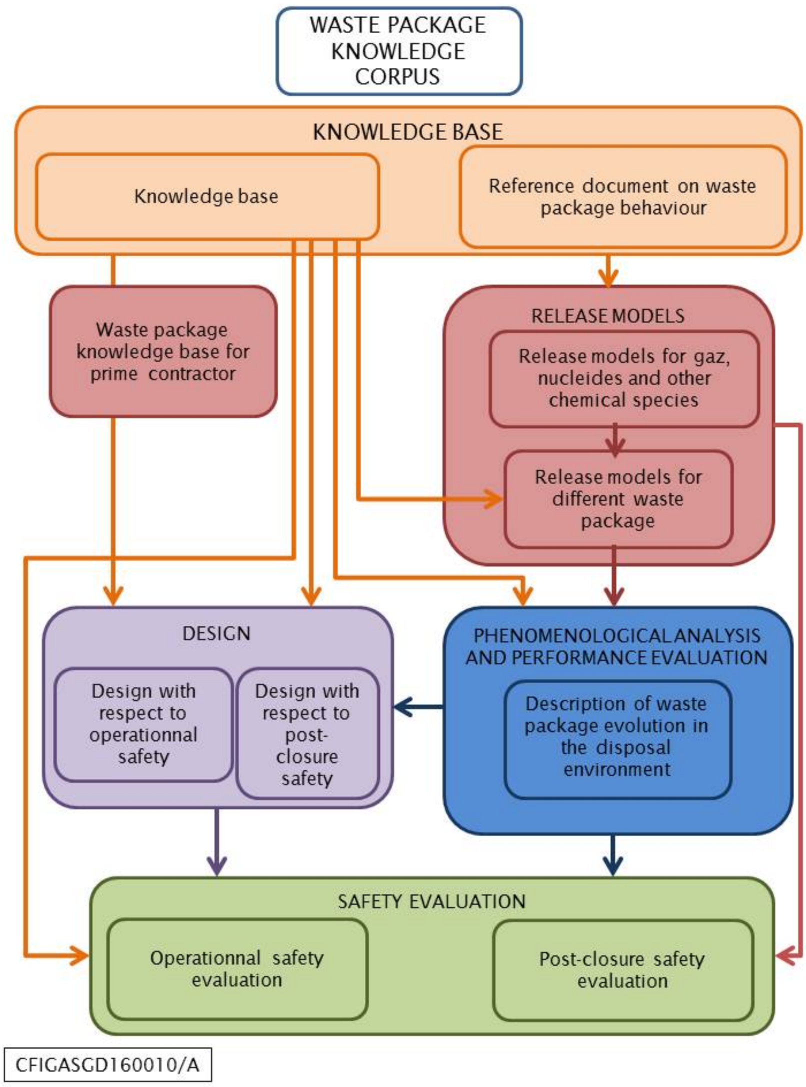

Figure 1.6-1 Process of the use of knowledge on primary packages intended for Cigeo

Thus, for Cigeo's design and its safety demonstration, the input data on knowledge about the primary packages to be emplaced within the facility are taken directly from this knowledge base:

- By using "raw" data (for the design of the disposal containers).
- By selecting design characteristics where required (with respect to the risks).
- By applying, where appropriate, margins to take uncertainties into account (application example given in Volume II of the DOS-AF on the radiological inventory).

This knowledge correspond to a wide array of waste of different types and characteristics.

It is therefore necessary to identify the package families and, specifically, the characteristics to be factored into the design of the facilities and the associated safety assessment that make it possible to cover this variability.

Beyond the various risks that lead each to a selection, the breakdown and distribution of the scope of analysis for the package families differ according to the location or component in question or the method used. For example, the surface facilities used in particular to condition primary packages into disposal package are selected both for the primary packages and the disposal packages. The components necessary to transfer the packages to the underground facility and emplace them into the disposal cells are selected based on the disposal package. Where appropriate, they are selected based on primary packages that do not require a disposal container prior to emplacement within a disposal cell.

Furthermore, the selected design options may lead to the decision to group waste types together, such as grouping several package families within the same transfer cask model or grouping some families of waste within the same buffer area or a cell. Thus, no single solution exists for each risk and each waste families (ILW-LL/HLW). Rather, there are several depending on the aim, i.e. the design of the surface or underground infrastructure and its associated equipment.

1.6.2 **Input data: knowledge on packages**

1.6.2.1 Knowledge base

Andra possesses a fixed reference set, that is shared within the agency, of knowledge on current and future waste and primary waste packages. This reference set is based on the various exercises (studies, choice of solution, inventories) and their consistency in ensured. Referred to as a 'knowledge base' this reference makes it possible to:

- Compile, validate, and control information collected through the Agency's various activities.
- Make this information available to users.
- All whilst guaranteeing the traceability of knowledge and changes to knowledge.

The 'knowledge base' consists of a knowledge database known as OSCAR.

1.6.2.2 Radiological inventories

Radioactivity is reported for each radionuclide[29] and each type (expressed in Bq/package at least).

The radiological inventory is reported for 144 radionuclides comprising fission products, activation products, and actinides. The various radionuclides are characterised by their radioactive half-life. They are thus divided into:

- 44 short-lived radionuclides with a radioactive half-life of less than 6 years (31%).
- 16 intermediate-lived radionuclides with a radioactive half-life of between 7 and 31 years (11%).
- 84 long-lived radionuclides with a radioactive half-life of at least 31 years (58%).

The design of the facility's components and the risk assessment are conducted using two types of radiological inventory — the nominal radiological inventory and the maximum radiological inventory. This information is required to ensure that the values used to design the facility's components are sufficiently bounding (radiation protection and ventilation systems in particular).

[29] The reporting thresholds that apply to Cigeo conform to the following rule :
- Radionuclides with a half-life of less than 6 years: 10 Bq/g.
- Radionuclides with a half-life of at least 6 years and but no more than 31 years: 1 Bq/g.
- Radionuclides with a half-life of at least 31 years: 0.1 Bq/g.

Depending on the family, values are provided as maximum activities for each radionuclide present or as variability factors (ratio of the maximum activity to the average activity). The maximum radiological inventory is calculated from these values by decaying them in order to use them at the repository's commissioning, thus as early as possible for ILW-LL and HLW0 then for HLW1/HLW2 (i.e. beyond 2075 for HLW1/HLW2 families). This bounding assumption makes it possible to dispense with the delivery schedule for the repository's design and provide margins for the future.

During the preparation of the safety analysis report, which will be used as a support document for the construction licence application, these margins will be assessed in particular for package families that primarily contain short-lived radionuclides (case of cobalt-60, which has a radioactive half-life of 5 years). The radioactive decay of these radionuclides may be significant and not taken into account at this stage of the design of the safeguards.

If the maximum activity of a waste type is unknown, the maximum radiological inventory used for design and assessments is the nominal radiological inventory without any consideration for decay over time.

The radioactive half-lives of the various radionuclides are taken from the Joint Evaluated Fission and Fusion File (JEFF).

1.6.2.3 Inventory of gaseous radionuclides

Hydrogen-3, carbon-14, and krypton-85 are the gaseous radionuclides considered for assessments of the impact of potential gaseous discharges. Their inventories are based on reports made by waste generators. These reports are available in the knowledge base.

Based on the release fractions associated with the gaseous radionuclides, off-gassing orders of magnitude for package are selected to assess the impact on the people.

1.6.2.4 Inventory of other gases

Some ILW-LL packages emit gases that cause radiolysis (effect of ionizing radiation emitted by radioactive substances on hydrogenated products present in the same packages (organic matter, water in the conditioning matrix)).

These radiolysis gases are primarily hydrogen. Their inventory with respect to the discharge of radiolysis gases from waste packages and the associated potential risk of explosion is presented in Section 1.6.3.5.

1.6.2.5 Inventory of toxic elements

The list of the relevant toxic elements is as follows: lead (Pb), boron (B), nickel (Ni), chromium (Cr [including Cr VI]), arsenic (As), antimony (Sb), selenium (Se), cadmium (Cd), mercury (Hg), beryllium (Be), CN radical, uranium (U) and asbestos. Their amounts are expressed in g/package for each chemical element.

The presence or absence of toxic elements in the primary waste packages is also systematically reported by waste generators.

The inventory of toxic elements has no effect on Cigeo's design. It will be used in the construction licence application to measure the potential impacts and verify that objectives for protection against toxic chemicals (see Volume I) are met.

1.6.3 Design characteristics

1.6.3.1 Geometric design characteristics for components/equipment

The design characteristics of the primary packages for the disposal containers are weight and geometry.

This "raw" data make it possible to define various container models for standardisation purposes in order to reduce the number of different models. Once the disposal containers are defined, each specification plan (inner and outer dimensions) established for each disposal container becomes a specific requirement that will be included in the acceptance specifications for the primary packages.

The table in the appendix presents, for each type, the weights selected in relation with their intended disposal container in solution 1 (referred to as the "reference" solution).

1.6.3.2 Design characteristics with respect to physicochemical co-disposal

In order to optimise Cigeo's design and, specifically, the distribution of the ILW-LL packages within the disposal cells and, as a result, the number of ILW-LL disposal cells, the package families have been grouped into seven physicochemical categories. All the packages in the same category, regardless of their type, are considered to be physicochemically co-disposable.

The seven categories are as follows:

- ILW-LL1: waste packages containing a significant amount of salts excluding bituminised sludge packages.
- ILW-LL2: bituminised sludge packages.
- ILW-LL3: packages containing waste (or another package component excluding the matrix) composed of organic matter.
- ILW-LL4: packages of non-exothermic or slightly exothermic cemented waste containing neither organic matter[30] nor salts.
- ILW-LL5[31]: packages of non-exothermic or slightly exothermic non-cemented waste[32] containing neither organic matter[33] nor salts, in particular structural waste from fuel reprocessing.
- ILW-LL6: packages of vitrified, non-exothermic or slightly exothermic waste, optionally after storage to reduce their decay heat and downgrade them from HLW0.
- ILW-LL7: packages of sodium waste[34] .

The distribution of the families of primary package by category is provided in the table in the appendix.

1.6.3.3 Design characteristics with respect to the risk of external exposure to ionising radiation

The design of the radiological shieldings pertains in particular to the thicknesses of the walls, doors, and windows of the surface facilities, the radiation-protection docking facades and doors of the underground facility, and the transfer casks.

These shieldings are designed using the maximum radiological inventory for the waste families. This makes it possible to cover all the primary packages in the waste families considered for Cigeo's design.

During future studies relating to Cigeo's safety demonstration and detailed design, verifications will be conducted to ensure that the design of the radiological shieldings for each waste type provides the necessary margins that make it possible to fulfil the principle of radiation protection (ALARA) defined in Volume I herein.

At this stage, the characteristics of the following package families are to be considered in the design of radiological shieldings with respect to external exposure to photons and neutrons:

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[30] Except for labels on intermediate canisters, glue and paint.
[31] The possibility of co-disposing of ILW-LL4 and ILW-LL5 packages is currently being studied and will be confirmed in the construction licence application.
[32] Geopolymer matrices fall under this category.
[33] Except for labels on intermediate canisters, glue and paint.
[34] Sodium metal is prohibited in the current phase of the preliminary specifications.

- Portions of surface nuclear facilities where operations will be conducted on primary waste packages:
  - ✓ ILW-LL: waste families COG-100, COG-110, CEA-120, CEA-060, EDF-080 and ITER-010.
  - ✓ HLW0: waste families CEA-1080.
  - ✓ HLW1/2: waste families COG-800 and COG-200.
- For areas/equipment that will "host" disposal containers (CtS):
  - ✓ CtS1: CEA-140;
  - ✓ CtS2: COG-100, COG-110, CEA-060, CEA-120;
  - ✓ CtS3: COG-440 et COG-040 ;
  - ✓ CtS4: CEA-280, COG-020, CEA-1020, CEA-1021;
  - ✓ CtS5: EDF-080, EDF-090, ITER-010, CEA-080;
  - ✓ CtS6: CEA-450;
  - ✓ CtS7: CEA-231;
  - ✓ CtS HLW0: CEA-1080;
  - ✓ CtS HLW 1/2: COG-800 and COG-200.
- The characteristic quantities taken into account in designing ILW-LL casks to limit external exposure hazards are the maximum quantities of the waste package families contained in them:
  - ✓ Type 1 cask with CS2 and CS3 disposal packages.
  - ✓ Type 2 cask with CS1, CS4, CS6 and CS7 disposal packages.
  - ✓ Type 3 cask with CS5 disposal packages.
- The characteristic quantities taken into account in designing HLW casks to limit external exposure hazards are the maximum quantities of the waste package families contained in them.

Note regarding the design of HLW containers: the thickness of the HLW container is determined by the post-closure safety requirements (see Volume II of the DOS-AF). Consequently, the design of the equipment and casks will be determined by the activity of the HLW type considered and the mitigation provided by the HLW disposal container (see Section 1.5 herein).

Table 1.6-1 Assessment of the characteristic quantities with respect to external exposure to ionising radiation.

External exposure hazard			
CS category	**Designed area**	**Activity (Bq/package)**	**Characteristic quantities (ambient dose equivalent rate 1 m away from a package)**
ILW-LL and HLW0	EP1 building	ILW-LL: 1,90E+15 HLW0: 5,71E+15	ILW-LL: In CP: 19 Sv/h (p); 50 µSv/h (n) In CS: 310 mSv/h (p); 5 µSv/h (n) HLW0: In CP: 31 Sv/h (p); 2 mSv/h (n) In CS: 1.3 Sv/h (p); 1 mSv/h (n)
HLW 1/2	EP2 building	2,02E+16 8,11E+15	In CP: 43.3 Sv/h (p); 6 mSv/h (n) In CS: 5.5 Sv/h (p); 7 mSv/h (n)
CS 1	EP1 building Cask 2 ILW-LL section	2,59E+12	In CP: 1.26 mSv/h (p); 0.1 µSv/h (n) In CS: 0.06 mSv/h (p); 0.02 µSv/h (n)
CS 2	EP1 building Cask 1 ILW-LL section	9,43E+14	In CP: 5 Sv/h (p); 50 µSv/h (n) In CS: 245 mSv/h (p); 5 µSv/h (n)
CS 3	EP1 building Cask 1 ILW-LL section	6,3E+13	In CP: 54 mSv/h (p); 0.8 µSv/h (n) In CS: 3 mSv/h (p); 0.1 µSv/h (n)
CS 4	EP1 building Cask 2 ILW-LL section	1,63E+14 1,43E+13 5,09E+13	In CP: 420 mSv/h (p); 2 µSv/h (n) In CS: 25 mSv/h (p); 0.5 µSv/h (n)
CS 5	EP1 building Cask 3 ILW-LL section	4,33E+15 1,90E+15 5,26E+13	In CP: 19 Sv/h (p); 1 µSv/h (n) In CS: 310 mSv/h (p); 0.04 µSv/h (n)
CS 6	EP1 building Cask 2 ILW-LL section	6,01E+11	In CP: 0.35 mSv/h (p); 0.001 µSv/h (n) In CS: 0.02 mSv/h (p); 0.001 µSv/h (n)
CS 7	EP1 building Cask 2 ILW-LL section	1,18E+12	In CP: 0.2 µSv/h (p); <0.01 µSv/h (n) In CS: 0.1 µSv/h (p); <0.01 µSv/h (n)
HLW0	EP1 building HLW0 cask HLW0 disposal section	5,71E+15 9,24E+14	In CP: 31 Sv/h (p); 2 mSv/h (n) In CS: 1.3 Sv/h (p); 1 mSv/h (n)
HLW 1/2	EP1 building HLW 1/2 cask HLW 1/2 section	2,02E+16 8,11E+15	In CP: 127 Sv/h (p); 10 mSv/h (n) In CS: 5.5 Sv/h (p); 7 mSv/h (n)

1.6.3.4 Design characteristics with respect to the risk of dispersion of radioactive substances

The ventilation classes (portions of surface facilities, drifts and cells in the underground facility) and the containment performance assigned to ILW-LL transfer casks are determined by considering the package families on the basis of the criteria given below and by using the maximum radiological inventory.

The selection of the package families with respect to the dispersion risk of radioactive substances is conducted for the following two accident conditions (see Volume III herein):

- Drop or collision resulting in resuspension of a portion of the contents of the primary package or disposal package.
- Fire involving a primary package or a disposal package and resulting in resuspension of removable surface contamination present on the primary container or the disposal container.

The selection criterion for protecting package families from this risk is air contamination (number of DAC) in consideration of the following information:

- The drop resistance of primary packages and the associated height used to prevent the resuspension of radioactive substances.
- The fire performance of the primary package and the sensitivity of the waste and its conditioning to rising temperatures is assumed to be sufficient to prevent the release of the source term inside the package.

<u>Design characteristics with respect to drops</u>

The package families that are most design-critical with respect to the risk of dispersion associated with resuspension of the activity in the primary and disposal packages in drop situations are presented in Table 1.6-.

Table 1.6-2 Assessment of the characteristic quantities with respect to the dispersion of the activity of a package following a drop from a height greater than its qualification height

Dispersion of activity from a package following a drop, impact, or collision greater than its qualification height				
Drop qualification height	**CS category**	**Bounding package families during accident conditions (drop, impact, collision)**	**Characteristic quantities (Atmospheric contamination caused by suspension of the activity in a CP/CS, expressed in No. DAC.m3)**	**Immobilisation or embedment matrix**
None	CS 5.1	CEA-1510	9,76E+08 / 9,76E+06	Mortar
	CS 6	CEA-300, CEA-290	1,51E+06 / 1,51E+04	Mortar
1.2 m	CS 1	CEA-140	7,42E+07 / 1,48E+06	Mortar
	CS 2	COG-030, COG-050	4,88E+07 / 4,88E+05	Mortar
	CS 4	CEA-1010, CEA-1000	3,23E+05 / 1,29E+04	Bitumen
		CEA-1020 and 1021	9,11E+05 / 3,64E+04	Bitumen
	CS 5	CEA-050, CEA-090	2,19E+08 / 2,19E+06	Mortar
	CS 7	CEA-231	4,32E+07 / 8,64E+05	Not defined
1.3 m	CS 5.3	EDF-080	1,62E+08 / 1,62E+06	Mortar
1.8 m	CS 4	CEA-280	1,03E+09 / 4,12E+07	Mortar
2.5 m	CS 6	CEA-450	5,46E+05 / 5,46E+03	Mortar
4.5 m	CS 4	COG-020	6,42E+05 / 2,57E+04	Bitumen
6 m	CS 3	COG-440	6,11E+06 / 6,11E+04	Mortar
	CS 2.3	CEA-110	4,46E+07 / 8,92E+05	Mortar
7.3 m	CS 5	COG-430	1,86E+07 / 7,44E+05	Not defined
7.5 to 8 m	CS 2	CEA-060	7,69E+08 / 1,54E+07	Mortar
9 m	CS 2	COG-120, COG-110	1,61E+08 / 6,44E+06	Not defined

Design characteristics with respect to fire

The package families that are most conservative with respect to the risk of dispersion associated with suspension of removable contamination potentially present on the outer surfaces of primary and disposal packages in fire situations are presented in Table 1.6-.

Table 1.6-3 Assessment of the characteristic quantities with respect to the dispersion of removable surface contamination in the event of a fire

Dispersion of removable surface contamination from a package in the event of a fire				
CS Category	Bounding package families under normal conditions	Maximum surface area of the CP/CS packages (cm²)	Maximum surface contamination (No. LDCA.m^3.cm^{-2})	Characteristic quantities (No. DAC.m^3)
CS 1	CEA-140	1,58E+04 / 1,74E+05	6,77E-03	1,07E+02 / 1,18E+03
CS 2	CEA-110, CEA-060	6,28E+04 / 1,73E+05	8,06E-03	5,06E+02 / 1,39E+03
CS 3	COG-440	7,59E+04 / 1,86E+05	3,21E-03	2,44E+02 / 5,97E+02
CS 4	CEA-280	3,00E+04 / 2,15E+05	7,56E-03	2,27E+02 / 1,62E+03
CS 5	CEA-1510, CEA-1100	8,80E+04 / 2,08E+05	8,33E-03	7,33E+02 / 1,73E+03
CS 6	CEA-450	1,17E+05 / 2,34E+05	7,68E-03	8,61E+02 / 1,72E+03
CS 7	CEA-231	2,10E+05 / 2,82E+05	2,72E-03	5,69E+02 / 7,64E+02
HLW	CEA-1190	9,31E+03 / 5,15E+04	7,79E-03	7,25E+01 / 4,01E+02

Regarding the dispersion of the radioactivity contained in the disposal packages in the event of a fire, it is considered that the protection afforded by the container and the measures for mitigating the intensity and duration of the fire do not make it possible to reach a temperature high enough to release of radioactive substances other than gases (tritium, carbon, argon, krypton). The packages most susceptible to a rise in temperature are bituminised waste packages. They were assessed in a specific programme between 2012 and 2015. The key teachings of this programme are presented below.

<u>Specific features of packages of bituminised waste</u>

The programme of studies conducted by Andra, Areva, CEA, and EDF made it possible to:

- Increase knowledge on the behaviour of bituminised waste during rises in temperature.
- Assess the level of thermal protection afforded by disposal container with respect to temperature loads on primary packages.
- Demonstrate sufficient mechanical behaviour of the disposal containers during fire and post-fire conditions.

The summary of this programme and the key test results are presented in the summary report on the results of the joint study on bituminised sludge (30).

- ***Knowledge on the behaviour of bituminised waste***

The teachings of the tests, conduct at various scales, made it possible to deepen understanding about the behaviour of bituminised waste during rises in temperature. The microcalorimetry tests made it possible to determine the temperatures that trigger chemical reactions, the energy that is released, and the rate of restitution of this energy.

The medium-scale tests made it possible to understand the mode of diffusion of heat within the bitumen and specified its diffusivity values. They also made it possible to understand the behaviour-change phenomena related to temperature-dependant variations in viscosity. Associated with thermogravimetric analysis experiments, they made it possible to identify the onset temperatures of pyrolysis phenomena.

It was thus possible to set the safety-important elements for bituminised waste packages taken at ambient temperature and subsequently heated:

- The presence of air in sufficient quantity is necessary in order for combustion of the bitumen to continue.
- The temperature-rise tests showed that the autoignition phenomena require temperatures above 300°C, for no ignition occurred during the tests conducted up to this value. A specific test showed that a wall temperature of 400°C triggers this phenomenon in environments where oxygen is present in sufficient amounts.
- Concentrations of a few percentages of CxHy gas were measured above 230°C. This temperature is the flash point for bitumen penetration grade 70/100 used for bituminised waste. The limit of 230°C is used to consider the ignition of bitumen in the presence of an ignition source applied to its surface.
- The tests made it possible to observe that, when heated up to temperatures of less than 200°C, no pyrolysis gases were emitted from the bitumen.

It terms of safety, it is considered that if the autoignition or flash point conditions are achieved at one point, they may lead to complete combustion of the bitumen if air is present in sufficient quantity. Temperatures sustained above 200°C do not lead to total loss of the bitumen over time, but to emission of gaseous compounds (pyrolysable or otherwise). This phenomenon is local and stops if the temperature drops. In the event of heating from an external source, pyrolysis results in the emission of gaseous compounds only on free surfaces. Dispersion occurs only with compounds that are volatile at the considered temperature.

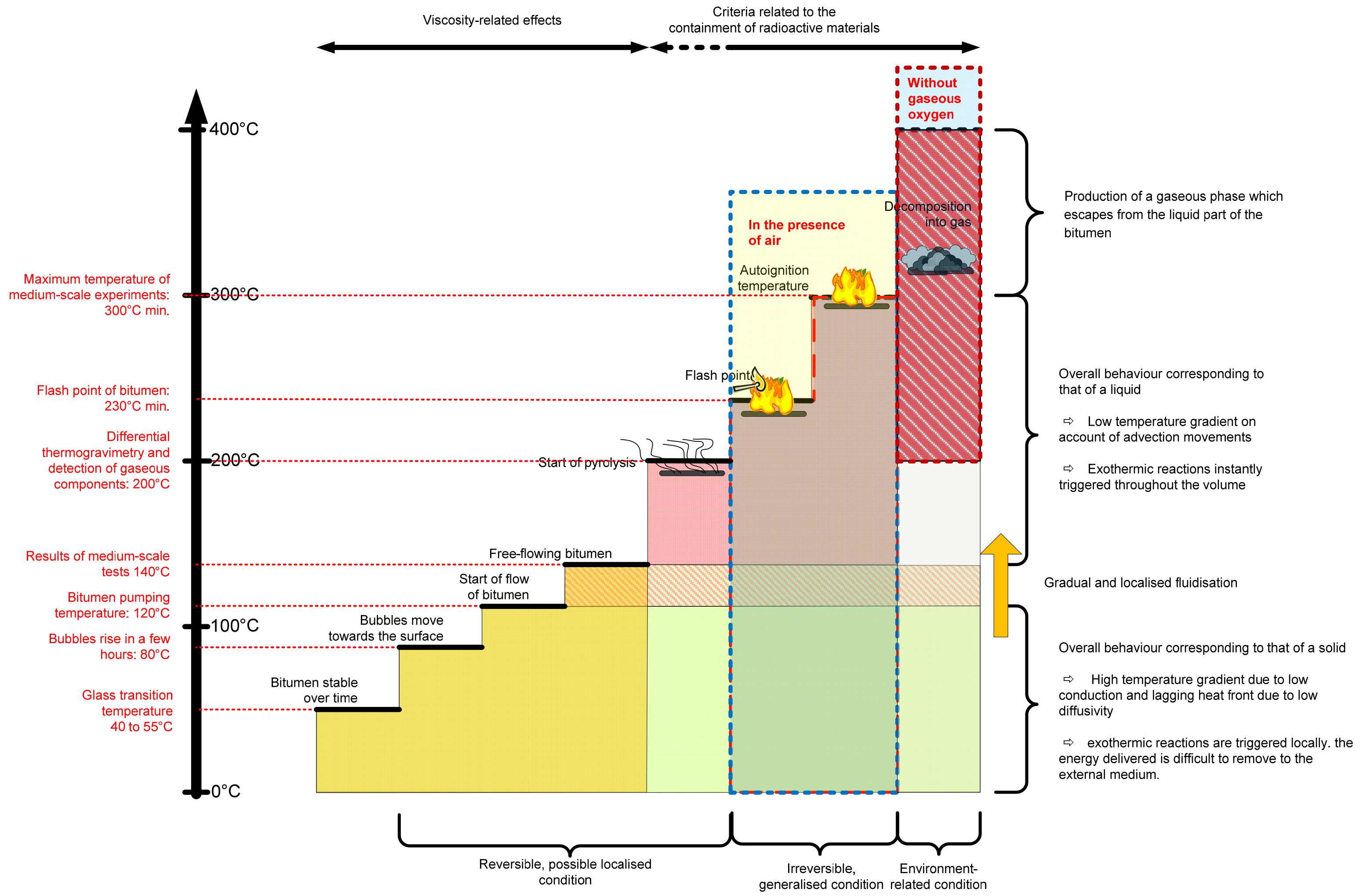

Figure 1.6-2 *Safety criterion associated with a bituminised sludge package*

- ***Behaviour of the containers***

A programme was conducted to test the behaviour of a disposal package comprising a full-scale concrete container containing four drums of bituminised waste under conditions representative of the bounding conditions for a fire within Cigeo. This test programme made it possible to:

- Assess the consequences of fire on the mechanical strength of the package and demonstrate its retrievability in particular.
- Characterise the diffusion of heat within the package.

Two types of test associated with various fire conditions were conducted:

- A configuration reproducing the thermal effects on the package surfaces according to the one-hour ISO 834 standard time–temperature curve used for building materials and elements.
- A configuration from a bounding fire involving a disposal package under the worst-case condition of Cigeo's operation.

The tests were conducted using a full-scale disposal container representative, in terms of its mechanical properties, of the disposal container design selected at the outline stage for Cigeo, and having a concrete thickness of 10 to 12 cm and 20 cm.

The results of the tests confirmed that the disposal package subjected to this maximised thermal environment remained handleable and thus retrievable. Indeed, the packages subjected to these tests could be handled via bridge crane and transported via forklift without showing any internal failure or damage in addition to that related to the tests.

Regarding the thermal protection of the drums of bituminised waste, the disposal containers limit the rise in temperature on the surfaces of the bitumen. During the tests, the maximum temperatures measured on the outer walls of the drums of bituminised waste within the disposal package did not exceed 125°C.

Visual inspection of the drums of bituminised waste, conducted after the disposal container was tested and opened, confirmed that the temperatures measured on the walls of the drums and inside the bituminised waste were not high.

A new ISO 834 one-hour test was conducted in June 2015 on a prototype CS4 package. The test conditions were similar to those conducted during the bitumen programme. The pictures in the figure below show the disposal package that was tested. Left: the package during preparation. Middle: view of a corner of the package and thermal environment within the furnace during the test. Right: the tested and cooled package.

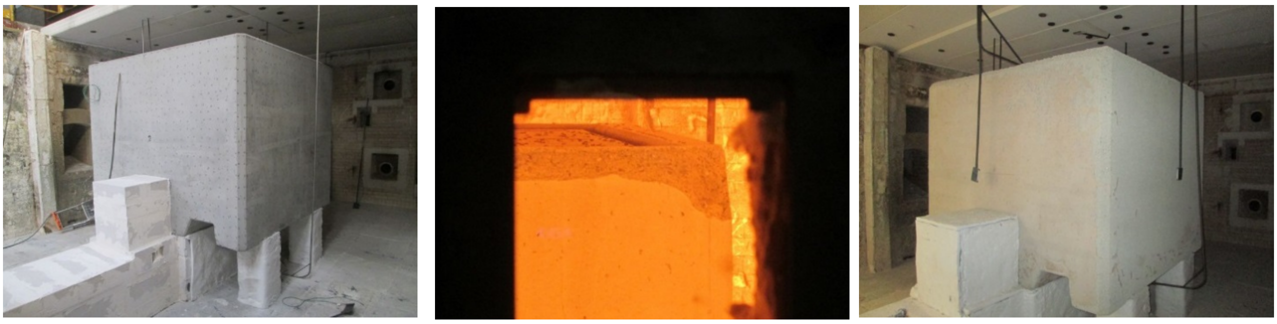

Figure 1.6-3 *Fire test conducted in an accredited fire-testing laboratory (French staff) on a CS4 package containing four drums of bituminised waste.*

The surface temperature of the drums of bituminised waste did not exceed 100°C. The only exception was the top portion of the drums, which contained only air and which remained below 110°C.

These tests also made it possible to assess scabbing of the concrete comparing two formulations (with and without polypropylene fibres).

The key teachings of these tests are the choice of concrete containing polypropylene fibres to effectively mitigate scabbing and improve the fire performance of the disposal container.

- ***Changes to the criterion***

The 100°C criterion used for the previous studies and associated with the loss of containment was changed in the light of the results of the test programme.

The various temperatures shown in the previous figure (see Andra, Areva, CEA, and EDF joint report) make it possible to define safety criteria according to the specific risks of each associated facility.

A temperature of 200°C in the presence of air and an ignition source near the drum surface make it possible to have a margin of at least 30°C with respect to loss of the containment matrix from combustion.

A temperature of 180°C on the surface of the drum makes it possible to have a margin of 20°C with respect to the formation of pyrolysis products as well as maintain containment regardless of the duration of the fire.

Between the two, as the temperature rise times of the bitumen are very great, the loss of containment will be very gradual.

1.6.3.5 Design characteristics with respect to the removal of radiolysis gases from packages

The selection criterion used to select the design characteristics with respect to the risk of explosion is the flow of hydrogen per reported primary package. This relates only to ILW-LL waste, as HLW waste is placed within gas-tight containers. The adopted values may affect the design of the ventilation of the rooms/cells and the maximum allowable periods for restoring ventilation or working on package transfer means in their presence in the event of downtime. All these elements provide arguments for the relevance of retaining the explosion scenario to design the facility or to exclude it.

Ventilation makes it possible to remove radiolytic gases emitted by primary packages. Assessing the risk in the event of loss of ventilation requires identifying package families that release the most radiolysis gases, assimilated with dihydrogen. In the light of the available data on the off-gassing of primary packages, the decision is to analyse and assess the risks with an average value, conduct a sensitivity study with a bounding value, and apply both values for an entire type, expressed in l/package/year. The case of a limited number of packages in a type able to exceed the range of values selected for design and assessment of the consequences in terms of design and even operation is also considered.

Regarding the ILW-LL packages and based on the maximum values in the knowledge base:

- The value of 40 l per year and per disposal package is used.
- The possibility of considering, on a case-by-case basis, a limited number of packages with an off-gassing value greater than 40 l per year and per disposal package, all whilst complying with a mean cell value of 40 l per year and per disposal package, is used.
- A sensitivity study with an off-gassing rate of 100 l per year and per disposal package is used. This value makes it possible to assess the robustness of the design and the safety demonstration.

This range thus makes it possible to cover a limited number of potential batches of primary package for which the off-gassing rate may be greater than 100 l per year and per disposal package despite a waste generator implementing the best economic techniques available. Indeed, during operation, the distribution of disposed packages would remain below the range used to design the ventilation within the cell. Extra attention must be paid to the transfer of these packages in the safety demonstration.

The package families that emit the most radiolysis gases are listed in the following table.

Table 1.6-4 Characteristic quantities for risks related to releases of radiolysis gases

Representative packages	Off-gassing value (l/CP/year)	Number of CP/CS
CEA-1100	15.8 (in 2010)	1
CEA-050 and 090	10.5	1
CEA-330	33.3	1
CEA-1000 and 1010	2.2	4
CEA-120	15	2
CEA-110	13.6	2
CEA-060	7.1	2
CEA-480	3.9 (9.5 max.)	4
COG-030 and 050	31 (at date of generation)	1
COG-040	28 (in 1995)	1
COG-440	120[35]	1
COG-460	11	4
EDF-080 and EDF-090	87[36]	1

1.6.3.6 Design characteristics with respect to the decay heat of primary packages

Decay heat is an important item of input data for verifying the design of walls and supports, the arrangement of packages within the cells, and the distances to be kept between cells in order to comply with the criteria listed in Section 2.1.4 of Volume III and which include the following maximum temperatures:

- 90°C in the clay rock.
- 65°C in the cementitious compounds.

ILW-LL packages: using data from the knowledge base, several families of primary package are selected to cover all the disposal packages and their arrangement within the cells. The package families with highest average decay heat at a given date are selected. Depending on the case, the decay heat of packages sent to Cigeo may be limited in order to comply with the aforementioned thermal criteria.

In the case of ILW-LL packages that rapidly decay, the criterion of 15 W per primary package or 60 W per disposal package is stipulated at this stage for disposal configurations of four primary packages per disposal package and six disposal packages per cell section. Lower values may prove to be necessary for packages that slowly decay (presence ^{108m}Ag and ^{241}Pu) according to their arrangement in the disposal package and in the cell section.

Table 1.6- shows the average decay-heat values for the worst-case package families per disposal container at a reception date at the time of emplacement within Cigeo for ILW-LL (so as not to depend on the delivery schedules) then emplacement for HLW1/HLW2 and HLW0.

[35] This is a mean value, as some packages can achieve as much as 300 l per year.
[36] Amount potentially produced during the first year within the closed C1PG package without factoring in the storage period of the C1PG packages in the activated waste conditioning and storage facility (ICEDA).

Some packages will have to remain in storage at the producer's in order to meet the above-mentioned decay-heat levels on arrival. The relevant package families are listed in bold in Table 1.6-.

The values used to design the surface facilities for **HLW packages** are listed in Table 1.6-. The design of the HLW sections, established in the light of the thermal criteria listed in Section 2.1.4 of Volume III and interstitial pressure criteria, is based on an average linear decay heat per cell used to take a certain variability into account, with a maximum heat output of 300 W/CP for HLW0 packages and 500 W/CS for HLW1 and HLW2 packages.

Table 1.6-5 Decay heat of the worst-case package families per disposal container at a given date of reception within Cigeo[37].

ILW-LL CS model or HLW type	Nominal radiological inventory	
	Worst-case type	Output per CP/per CS (W)
1	CEA-070	0.07/0.15 (2 CP)
2.1	COG-030	0.42 (1 CP)
2.2	**COG-110**	**24/96 (4 CP)**
2.3	CEA-110	0.46/0.92 (2 CP)
2.4	CEA-1120	8.07/32.28 (4 CP)
3	COG-440	5.44 (1 CP)
4	CEA-280	0.646/2.59 (4 CP)
5.1	CEA-1510	4.70 (1 CP)
5.2	CEA-100	0.01 (1 CP)
5.3	**EDF-080**	**50 (1 CP)**
5.4	COG-400	6.15/24.6 (1 CP)
5 not defined	ITER-010	25.2 (1 CP)
6	CEA-450	1.17 (1 CP)
7	CEA-230	0.03 (1 CP)
HLW0	CEA-1080	276/552 (2 CP)
HA1&2	**COG-200/COG-800**	**763/580 (1 CP)**

1.6.3.7 Design of the facilities with respect to the criticality hazard

The number of disposal containers in each buffer area or cell and the arrangement of these containers must be identified in order to design the facilities for the criticality hazard.

The package families used to design the facilities for this hazard were selected based on the fissile materials present within the packages as well as the following information:

- Physicochemical nature and composition of the fissile medium.
- Weight of the fissile material.
- Geometric dimensions of the packages.
- Types of moderator and embedding matrix for the waste.

Andra uses this information to determine a reference fissile medium for the criticality risk analysis.

[37] Currently set at 2075 for HLW1 and HLW2.

The maximum weights of fissile material for each type of primary package identified based on the knowledge database during the basic engineering design studies (APS) are listed in Table 1.6- below.

Table 1.6-6 Maximum weights of fissile material by type of primary package.

Type of waste	Primary container	Weight per CP (g)	Further details
ILW-LL	218 l drum	122	Maximum allowable weight for stacked storage four layers-high on waste generator's site
	223 l drum	80	Maximum FM weight
	500 l concrete	80	Maximum FM weight
	500 l MI	200	Allowable weight: total 235U + Pu < 200 g
	870 l	200	Allowable weight: weight (235U+ 2 x 239Pu) < 200 g
	CAC	87.5	Maximum Pu weight
	CBF-C'2	70	Maximum Pu weight
	CSD-C	117.5	Maximum measured weight of ^{239}Pu
	EIP	283	Maximum weight of all fissile isotopes (12% of Pu)
HLW	175 l stainless steel canister	176	Maximum Pu weight
	150L AVM	110	Maximum Pu weight
	CSD-V	110	Maximum allowable Pu weight

2

The Site

2.1 General overview

The different scales of the site

Different terms are used to refer to the area of study and the wider geographical areas.

<u>The Paris basin</u> is the sedimentary system extending east to west from Lorraine to Normandy and south to north from Poitou to northern France.

<u>The Meuse/Haute-Marne sector</u> corresponds to a zone 40 km from east to west and 60 km from north to south centred on the Meuse/Haute-Marne Centre. To the east, south and west the sector is bounded by the Gondrecourt graben and the Marne faults.

<u>The transposition zone (ZT)</u> is defined as the area in which the properties of the Callovo-Oxfordian and the geology of the surrounding formations are similar to those determined on the site of the Meuse/Haute-Marne Centre. It covers an area of about 250 km².

In order to study the site of the underground facility, in 2009 Andra proposed to the Government a <u>Zone of interest for detailed reconnaissance (ZIRA)</u> of about 25 km² located within the transposition zone. The technical criteria taken into account relate to safety and geology (thickness of the layer, depth, orientations of environmental stresses, etc.). Criteria related to land-use planning and local integration of the project (such as compatibility with siting of the ramp on the Meuse/Haute-Marne border and with potential siting of the access shafts in a wooded area, avoidance of siting the facility under built-up areas in villages, etc.).

The <u>zones where surface facilities are located (ZIIS)</u> have been identified by Andra, taking account of the constraints associated with flood-risk areas, built-up areas, protected natural areas and flyover zones, etc. They consist of:

The repository access "<u>ramp zone</u>", covering an area of about 200 hectares, in an interdepartmental zone, on the Haute-Marne side bordering the Meuse department.

The "<u>shaft zone</u>", covering an area of about 110 hectares (excluding muck piles).

2.1.1 Scientific studies performed over many years to characterise the site

These studies have provided a better knowledge of the geological environment and the properties of the argillaceous rock. The acquisition of knowledge of the geological environment of the Meuse/Haute-Marne sector is based around several complementary approaches:

- over forty **boreholes** several hundred metres deep have confirmed the uniformity of the host formation and the absence of faults (Figure 2.1-1). The cores extracted from these boreholes were used to define the geometry of the layers forming the subsoil. They were also used to obtain more detailed knowledge of the geomechanical behaviour of the clay rock and to develop behaviour models in order to create rock damage forecasts depending on the type of construction used for the underground facility;
- various **seismic surveys** in 2D (1994-1996) and in 3D in 2000 (4 km²) and 2008-2010 (37 km²) on the site (Figure 2.1-2) have made it possible to define the precise arrangement of the layers and to characterise them (thickness, depth, dipping, etc.). They provided a far more detailed image of the volume of the site and confirmed that the Callovo-Oxfordian clay layer is regular with a thickness greater than 130 m and geometry consistent with the history of deposits that succeeded the Callovo-Oxfordian. These surveys also showed that there were no faults with vertical clearance in the Callovo-Oxfordian layer, nor in the overlying Oxfordian limestone;
- **ground studies** to observe the outcropping formations (at laboratory scale as well as Meuse/Haute-Marne sector scale), find out the main features of the geological environment, take samples and integrate the data into models (Figure 2.1-3);

- **analyses at the Underground Research Laboratory** at the Meuse/Haute-Marne Centre in order to test the methods and tools and to confirm the geological model with the support of sedimentological and microstructural data. Throughout the excavation of the shafts from August 2000, continuous measurements of all the formations crossed were used to establish a detailed geological map of the face over the full depth of the two shafts, to assess the lithological variability of the layers, at a scale of tens of metres, to observe the nature of the layers depending on direction, to characterise their natural fracturing and micro-fracturing and to assess the impact of this on the circulation of fluids. The observations made since the start of the shaft excavation works confirm the sedimentary and tectonic data already obtained by drilling and supply precise quantified structural data that confirm the geological model;
- the **Perennial Observatory of the Environment** (OPE) established from 2007 to provide a precise description of Cigeo's environment and to monitor its long-term development. The OPE has implemented a multi-disciplinary observation programme (water, air, flora, fauna, human aspects) for a period of at least 100 years. Its aim is (i) to provide an assessment of the environmental conditions of the disposal facility site, over a period of 10 years, in terms of physical and chemical aspects as well as biological and radiological characteristics, (ii) to record this environment for future use, (iii) to prepare an environmental monitoring plan for the future disposal facility, (iv) to understand the interactions between the different environmental mediums and monitor their development in order to produce a precise assessment of the disposal facility's impact and (v) to determine the origin of any disturbance observed.

This work aims to obtain a detailed understanding of the environment and geological medium at the Meuse/Haute-Marne site in order to (i) ensure that this area and, in particular, the Callovo-Oxfordian clay layer, has the required properties and to (ii) assess its long-term behaviour.

A knowledge of the site based on years of observation and reconnaissance.

The observations, measurements and analyses of the current condition of the site and the properties of the Callovo-Oxfordian clay layer have enabled us to produce a representation of the site that can be used on one hand to check that it is favourable and on the other to provide the data needed for design.

Figure 2.1-1 *Borehole EST442, target Dogger. Drilling with a down-the-hole hammer using inverse circulation (photo: Eric Poirot, Andra)*

Figure 2.1-2 *Seismic reflection survey around Andra's Laboratory (photo: Véronique Paul, Graphix)*

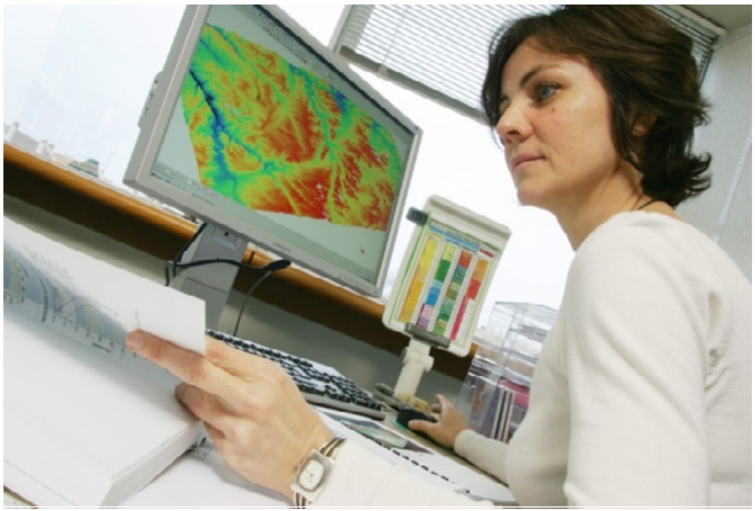

Figure 2.1-3 *Integration of data into the geological models (photo: Patrice Maurein)*

2.2 Geography and topography

The eastern part of the Paris basin, where the Meuse/Haute-Marne sector is located, is characterised by cuestas consisting of a succession of cuestas varying in height in line with the outcropping geological formations and topography. In this general context, the Meuse/Haute-Marne sector is an undulating plateau, drained by the valleys of the Seine basin and by the tributaries of the Meuse.

The sector that includes the ZIRA and ZIIS is the backslope portion of the Barrois limestone plateau (a geological formation dating from the upper Jurassic) with altitude varying from 300 to 400 m above sea level, located between the Saulx to the west and the Ornain to the east, water courses flowing from south to north. The surface of the plateau is structured by the valleys of the Saulx and its tributary the Orge, as well as by the narrower valley of the Ormançon, a tributary of the Ornain flowing in a general northerly direction.

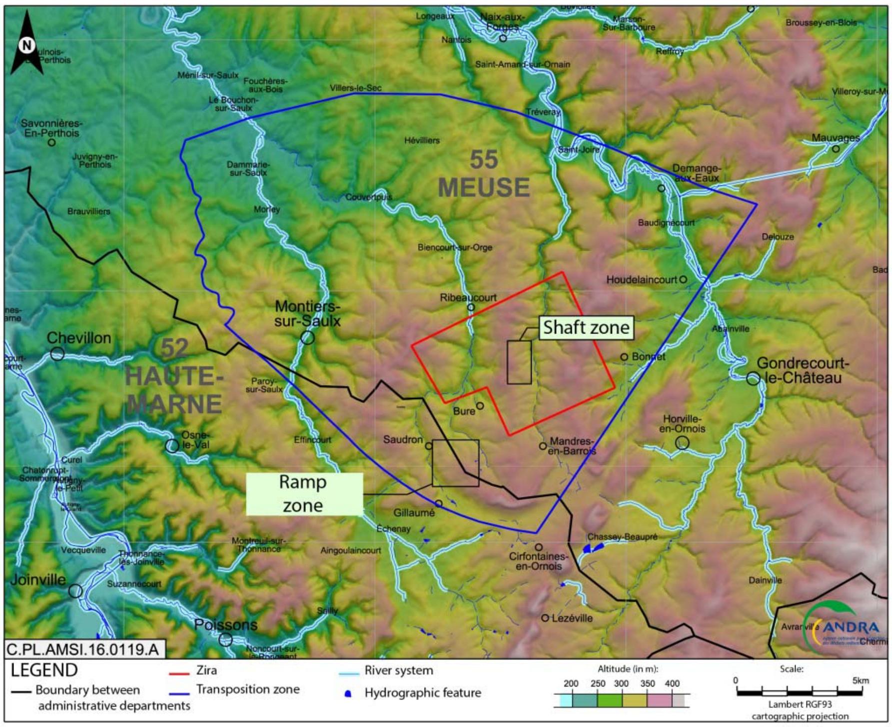

Figure 2.2-1 Topographical map of the sector

In the "shaft" zone located within the ZIRA, the relief is characterised by elevation changes of 60 to 80 metres between the high points of the landscape and the bottom of the Ormançon valley. This catchment area is marked by hills and valleys that collect runoff and carry it down to the Ormançon. The altitudes range from 360 to 340 metres. In the "ramp" zone, located on the slope of the Barrois limestone followed and intersected by the Orge valley, the relief is characterised by the bottom of the Orge valley at an altitude of 320 m and the slope, combined with the catchment area of the Orge valley, which has a fairly steady gradient with shallow gullies.

On the surface, between the "ramp" zone and Mandres-en-Barrois following the D60 and D960, an East-West section characterised by dry valleys and by the City farm valley can be seen. The elevation changes are in the region of 20 metres, with altitudes varying from 365 to 345 metres. Between the "shaft" zone and Mandres-en-Barrois (a former Roman road), there is a North-South section, marked by flat topography and small changes in elevation.

Topography of the site

In terms of Cigeo's operational phase, apart from the construction work associated with building the structures and surface infrastructure, which will cause slight local topographical modifications[38], no topographical changes or developments are expected because any external geodynamic phenomena produced by erosion or tectonic movements affecting the surface environment will be negligible over this time scale.

Consequently, the data used for designing the surface facilities reflect the current geography and topography described above.

[38] The profile of the terrain will be altered in order to ensure good stability of the uncovered ground and sympathetic integration of the facilities into the landscape

2.3 Geology and seismology

2.3.1 Geological and tectonic context

The Meuse/Haute-Marne site is on the eastern edge of the Paris basin. The general structure of this zone is a series of sedimentary layers (the oldest of which are located on the edges and at the bottom of the bowl and the most recent at the centre), predominantly consisting of clay and limestone deposited 250 million to 135 million years ago. This alternation explains the cuestas characteristic of the regional topography.

This thick sedimentary sequence has a regular dip of 1 to 1.5 degrees to the North-West, towards the centre of the Paris basin, with low-amplitude undulation oriented east-north-east/west-south-west.

In the Meuse/Haute-Marne sector, from bottom to top and from east to west at the outcrops, the sedimentary series consists of (Figure 2.3-1):

- the Dogger limestone formation overlying the Lias marls and clays;
- the Callovo-Oxfordian clay formation;
- the limestone formation of the middle to upper Oxfordian;
- the Kimmeridgian marl;
- the Tithonian (or Barrois) limestone outcrops in the sector;
- a few thin surface deposits of Cretaceous clay/sand, capping the highest topographical points.

Due to its intraplate location far from any active tectonic regions, the Paris basin has been affected very little by tectonic movements in the last 65 million years. It is a remarkable area of the West European plate, where the lithosphere has a stable uniform thickness and stands out for being practically aseismic.

Tectonic activity in the region of the Meuse Haute-Marne site is very small (low seismic activity, little crust displacement, unchanging stress orientations) and the geological structure is stable, as evidenced by the absence of quaternary indices of tectonic activity at the faults surrounding the study area.

Two major families of faults border the Meuse/Haute-Marne sector (Figure 2.3-1):

- the faults of the Joinville graben to the south-west of the sector and the Gondrecourt graben to the south-east, which are not rooted in the basement. They cut straight narrow graben into the Jurassic sedimentary cover and fade away deep in the base formations of the sedimentary cover (Triassic salts and Permian clay rock);
- faults in the basement of the Marne.

To the west of the sector, this regional fault system is subdivided into small faults and forms a diffuse fracture zone before disappearing towards the south-east, beyond the Gondrecourt graben.

Located within the block bounded by these faults, the ZIRA appears to be free from detectable faults in the Callovo-Oxfordian and its surrounding formations, demonstrated both by the surface mapping work and by the seismic reflection surveys of the ZIRA (detection threshold of 2 m with 3D seismic processing techniques).

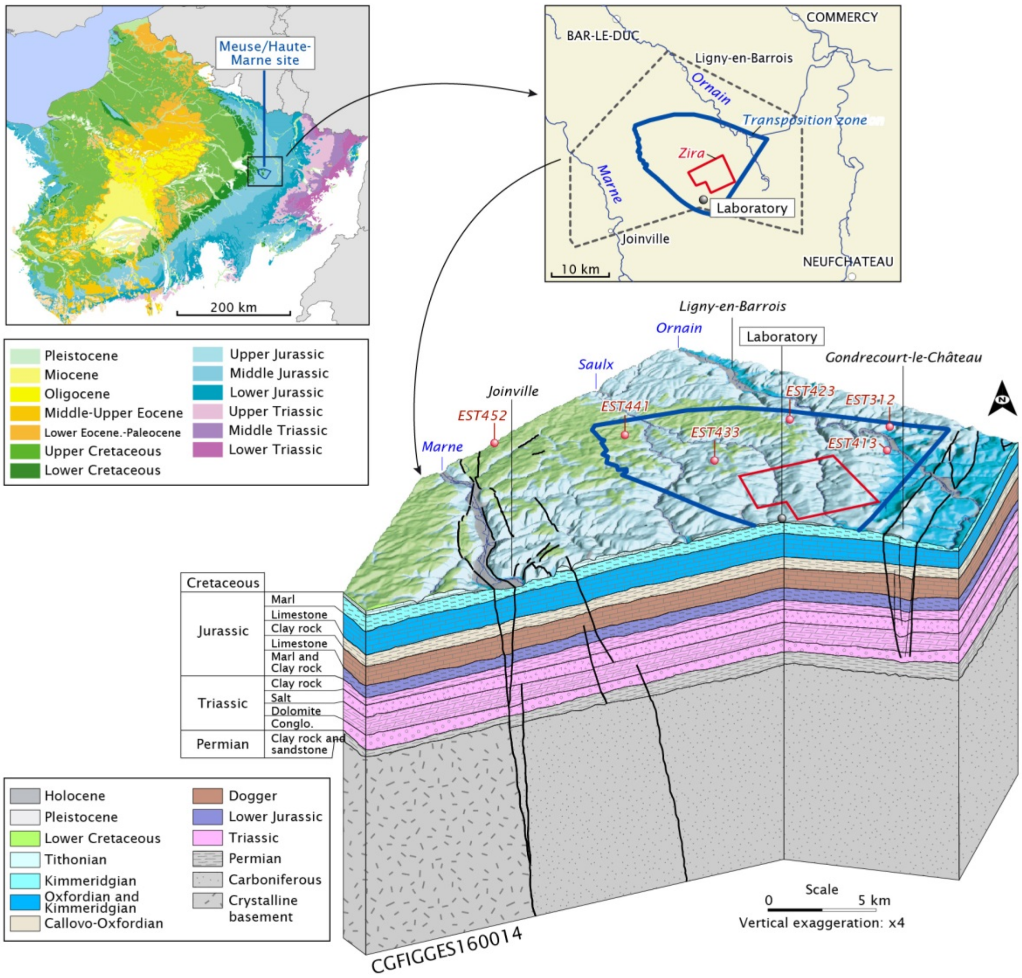

Figure 2.3-1 *3D geological block diagram of the Meuse/Haute Marne site and description of the series of geological formations*

Geological context

The Meuse/Haute-Marne site is on the eastern edge of the Paris basin. This is shaped like a bowl formed of a series of sedimentary layers, predominantly consisting of clay and limestone, more than 2000 m thick over the sector. There is a regular dip in the formations of 1 to 1.5° to the north-west, in the direction of the centre of the Paris basin.

Formation	Age	Average thickness for ZIRA	Characteristics
Barrois limestone	Tithonian 140 million years	39 m	Surface aquifer
Kimmeridgian marls	Kimmeridgian 145 million years	108 m	Impermeable
Oxfordian limestone	Upper to Middle Oxfordian 150 million years	275 m	Not very permeable
Callovo-Oxfordian clay rock	Lower Oxfordian-Upper to Middle Callovian 155 million years	153 m	Host formation
Dogger limestone	Lower Callovian-Dogger 165 million years	226 m	Not very permeable

2.3.2 Outcropping formations

There are Barrois limestone (upper Jurassic formation) outcrops over most of the Meuse/Haute-Marne sector. Their thickness, which varies in line with dip and topography, increases towards the north-north-west (Figure 2.3-2). The total thickness of the formation, consisting of five separate calcareous lithological levels, can be as much as 150 m when complete.

There is very low spatial variability in the composition and thickness of these units. The series at sector scale both describes and gives the thickness of the units at ZIRA scale, except for the topmost part (top few metres).

Because the formation is not very deep at the site, the stresses within it are close to the weight of the soil and are mainly affected by topography.

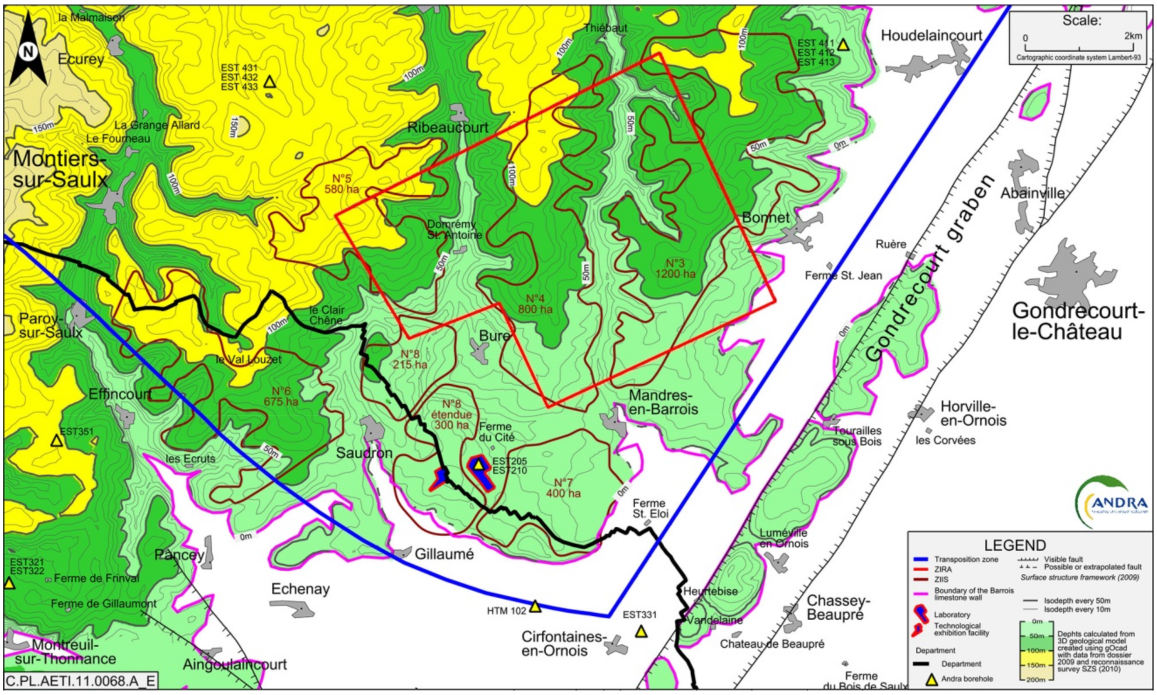

Figure 2.3-2 *Map showing the thickness of the Barrois limestone and the more recent formations (in the ZIRA, the thickness corresponds to the thickness of the Barrois limestone)*

The short boreholes drilled in the ZIRA and the surrounding area detected the presence of minor fractures, on a scale of millimetres to centimetres, combined with indicators of alterations, linked to the action of the climate (breakdown of rock by frost action and fracturing by freezing), down to depths of 15 - 20 m below the surface, and to widespread karstification phenomena.

2.3.3 Geological formations crossed by the surface-to-bottom connection structures

The ramps will pass through more than 450 m of geological formations of very different types and lithology (Figure 2.3-3).

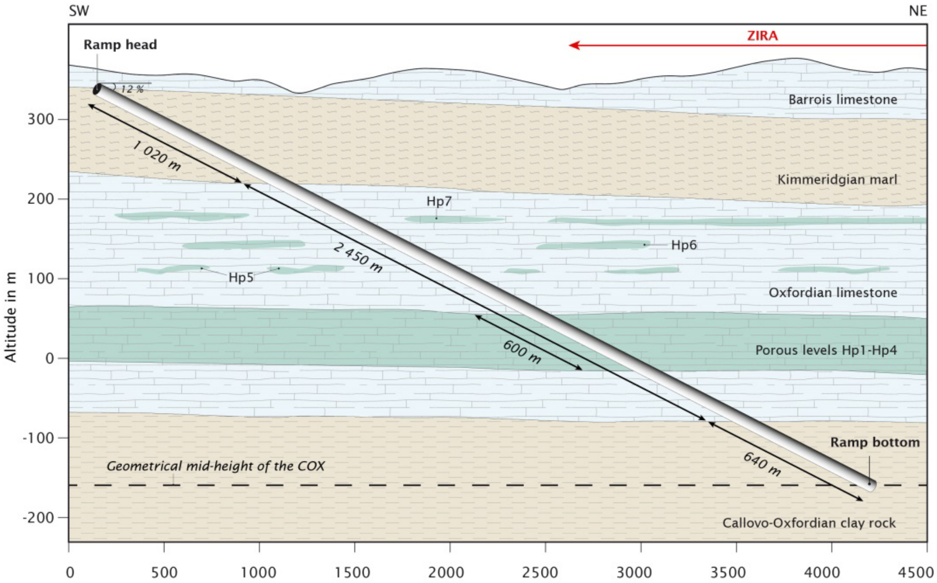

Figure 2.3-3 *Geological profile along ramps and estimation of linears for each formation passed through (produced in Godard 3D modeller, vertical scale x4)*

Kimmeridgian marl

There are Kimmeridgian marl outcrops on the eastern boundary of the transposition zone and in the south-eastern part of the ZIRA. The Kimmeridgian marl formation is characterised by the very regular overlaying of three clay/marl layers, each several tens of metres thick, separated by two beds of white limestone 10 to 15 metres thick. There are a few limestone levels around a metre thick between the clays and marls. In the ZIRA and adjacent areas ("ramp" zone), the total thickness of the Kimmeridgian marls is about 110 m.

In this formation, the convergence measurements taken in the main shaft of the Underground Research Laboratory show anisotropy of the horizontal stresses and the direction of the main stress to be N155°E, identical to that measured in the deeper formations and consistent with those shown at basin level.

Oxfordian limestone

The thickness of the formation increases slightly from east to west in the transposition zone (from 275 to 335 m). In the ZIRA, the average thickness of the formation is 280 metres.

The Oxfordian limestone is characterised by large variations in facies both vertically and laterally. The transition between the Callovo-Oxfordian and the limestone platform is gradual and expressed by marly clay facies for around twenty metres (C3a facies) with characteristics very similar to those at the top of the Callovo-Oxfordian formation.

The extent and the continuity of the various facies determine the distribution and extent of the porous levels or horizons (HP), aquifers, identified as having the highest permeabilities in this formation (above 10^{-8} m/s).

Data collected directly and indirectly show that the characteristics of the Oxfordian limestone in the ZIRA are in general equivalent to those determined at the Underground Research Laboratory in Bure:

- the first 20 metres of the Oxfordian limestone consist of argillaceous limestone with very similar characteristics to those of the silty-carbonated unit of the preceding Callovo-Oxfordian. Above this are some twenty metres of reef limestone of low permeability (10^{-11} m/s to 10^{-12} m/s);
- the overlying unit, around a hundred metres thick, combines fine porous and permeable (10^{-8} m/s to 10^{-7} m/s) facies and cementitious limestones of very low porosity and permeability. Vertically above the laboratory, these facies are divided into four discontinuous porous levels (HP1 to HP4) reaching a combined thickness of nearly 80 metres. The low connectivity of these levels may explain their low productivity;
- the next 100 m consist of a series of beds of a marly series intercalated between oolitic limestone levels. At the top of each of these limestone levels is a more porous and permeable level (HP5 to HP7) with thicknesses between 5 and 10 m and average permeability of around 10^{-7} m/s. At the laboratory level, the disturbances caused by draining of the shafts show that HP1 to HP4, HP5 and HP6 to HP7 are hydraulically independent. In the eastern and north-eastern parts, the grey marly series creates a clear separation between the lower (HP1 to HP4) and the higher (HP5 to HP7) aquifer levels. As the continuity of the "série grise" formation between the eastern part and the Laboratory is maintained, possible transfers between the lower and upper porous horizons and between each horizon HP5 to HP7 in the ZIRA should be limited. In the south-western part of the ZT, the negligible thickness or absence of this semi-permeable layer means that all the Oxfordian limestone formations, including the porous horizons, form only a single aquifer, generally with a single flow field;
- the last 30 m consist of limestones of low porosities and permeabilities.

In all the porous levels of the Oxfordian, both convective (horizontal) and diffusive transfers are represented.

2.3.4 Cigeo's host formation: the Callovo-Oxfordian

2.3.4.1 The geometry of the formation at ZIRA level: characteristics and variability

The Callovo-Oxfordian clay formation, dating from the Jurassic, was deposited about 160 million years ago over a period of about 5 million years, in an open and calm marine environment, below a water depth of about a hundred metres. It forms a predominantly clay layer between the limestone formations of the Dogger and the Oxfordian.

Its boundaries have been defined precisely by means of a large number of boreholes and seismic lines distributed uniformly over the whole of the sector studied.

- over the transposition zone, its thickness increases from 130 m to 162 m from south-west to north-east in line with the main direction from which the sediments came;
- in the ZIRA, it is between 142 m and 162 m from south-west to north-east, in line with the main direction from which the sediments came (Figure 2.3 4).

The top of the layer is 340 and 532 m deep (Figure 2.3-5), the middle between 420 and 604 m (Figure 2.3-4) and the base between 501 and 675 m. Around the shaft zone, the layer is 151 m thick and its top lies at a depth of 443 m.

The clay layer slopes slightly towards the north-west (1° on average) in line with the whole sedimentary pile in this part of the Paris basin. The uncertainty over the geometry is highly dependent on the proximity and number of calibration points. Currently, the depths of the layer in the ZIRA are estimated to the nearest 10 m, the thicknesses to the nearest 6 m.

In the ramps, taking account of a gradient of 12%, a length of about 3500 m separates the top of the ramps from the top of the Callovo-Oxfordian and it takes another 640 m to reach the bottom of the ramps.

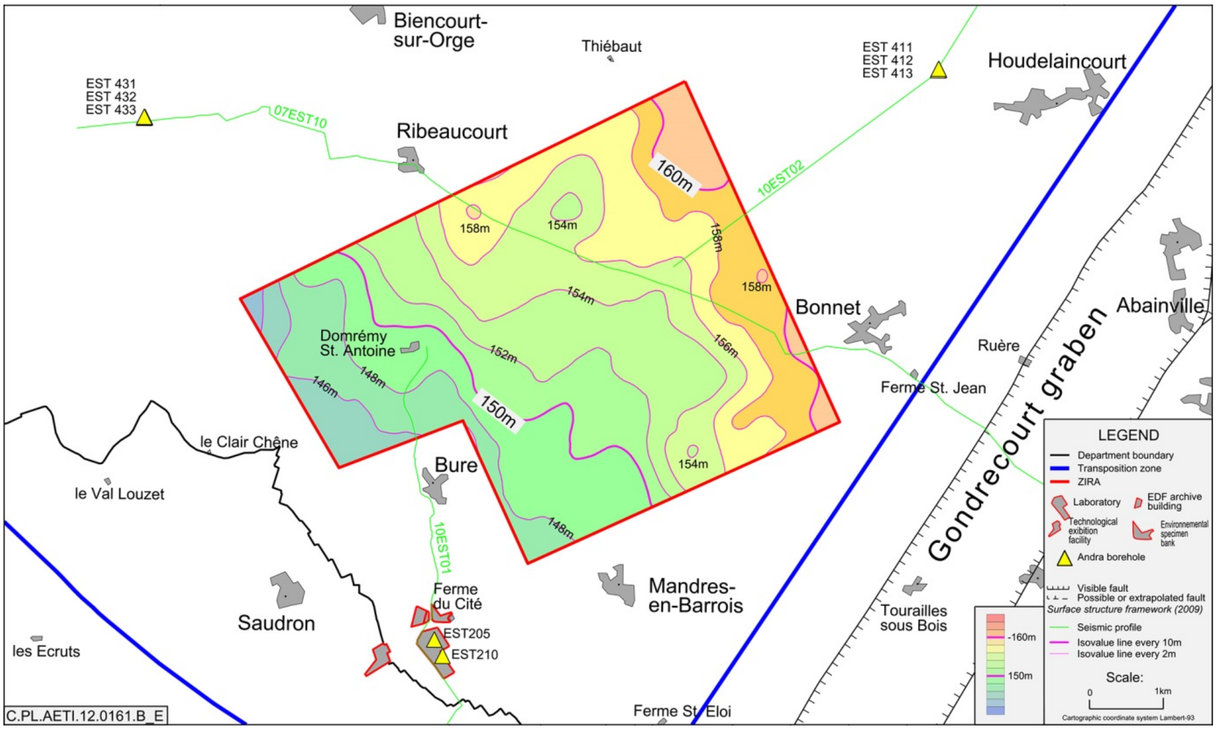

Figure 2.3-4 *Thickness of the Callovo-Oxfordian clay rock in the ZIRA (distance in metres between the base and the top of the formation)*

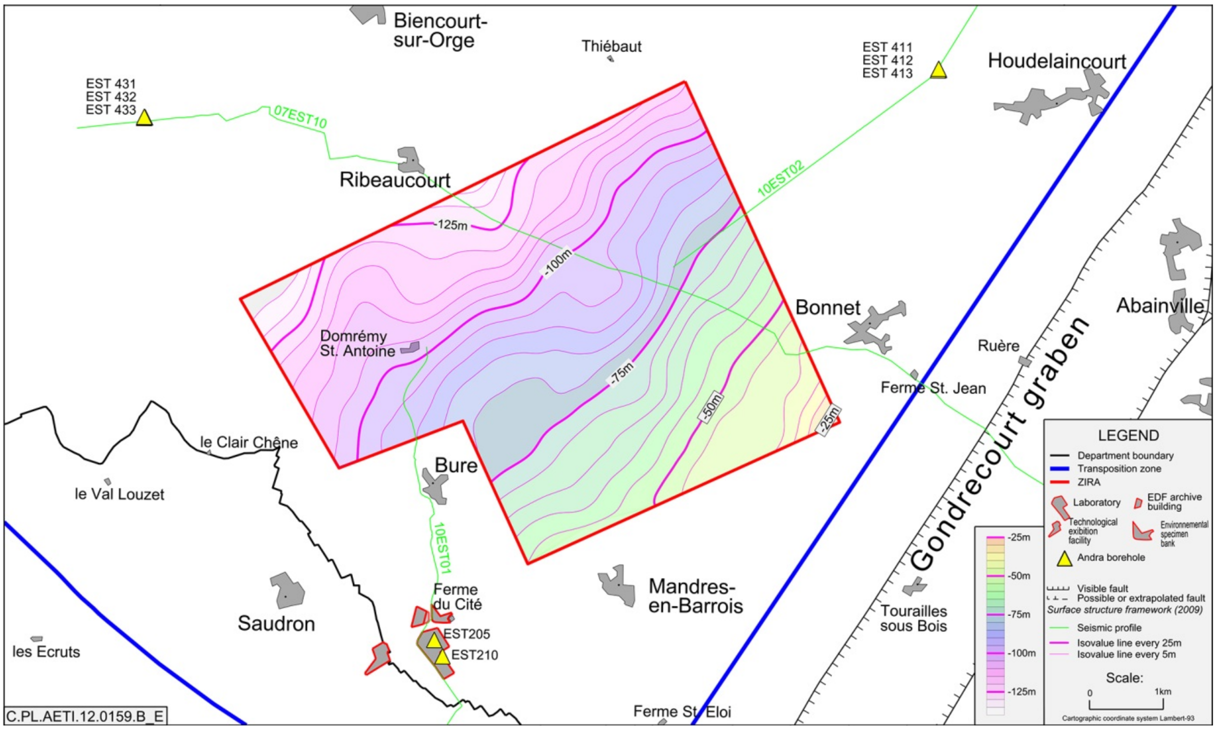

Figure 2.3-5 *Altitude of the top of the Callovo-Oxfordian in the ZIRA (m above sea level)*

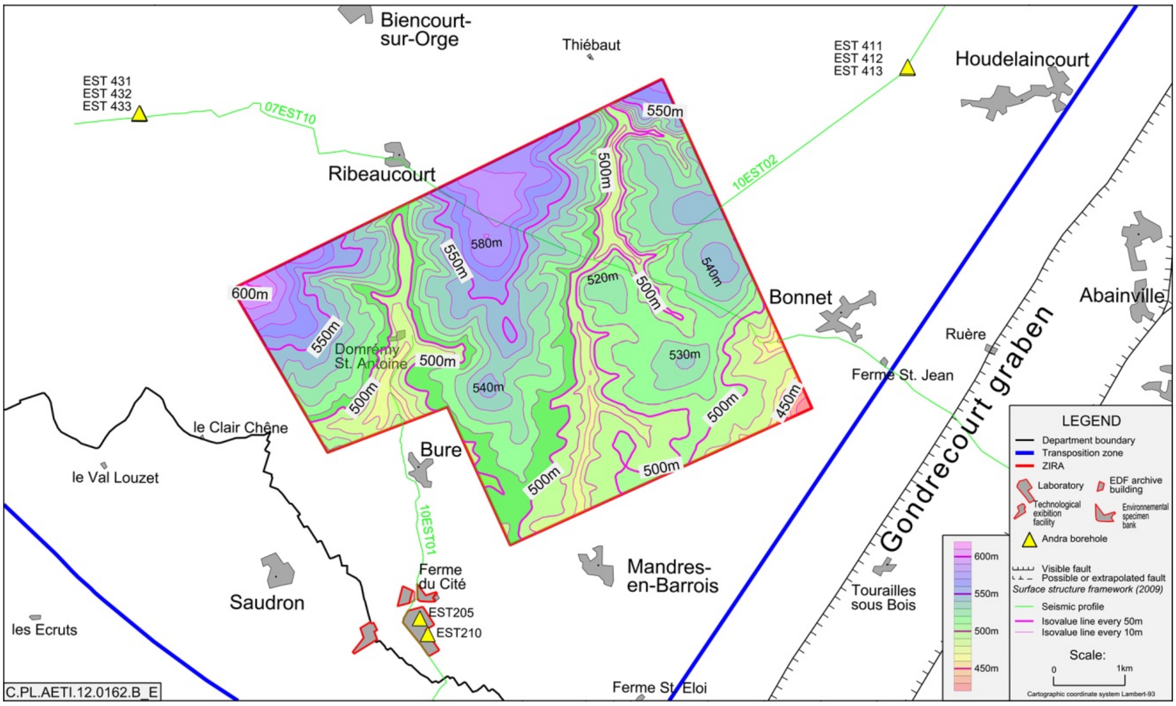

Figure 2.3-6 Depth of the Callovo-Oxfordian in the ZIRA

2.3.4.2 Properties of the formation

The formation is formed of three main mineralogical phases: a predominantly clayey phase (40% to 45% on average, up to 60% in the middle of the layer), a calcareous phase (mostly calcite, with a few percent of dolomite) and a quartz phase (of fine particle size: silts).

Vertically, the analyses always show the same small variations in the mineralogical composition of the rock: this proves that the sediments were deposited at the same time in the same type of environment and with the same intensity. The small variations in the proportions of the main mineralogical phases are organised into 3 continuous sedimentary sequences associated with fluctuations in the sea level throughout the period (transgressive/regressive cycle represented in right-hand column of Figure 2.3-7.

These gradual mineralogical variations coupled with the burial of the deposits are the main causes of the petrophysical variations in the layer. Nevertheless, the discrete diagenetic processes, regional in extent, were not able locally to alter significantly the characteristics of the Callovo-Oxfordian.

Three major geological units are identified and described from the bottom to the top of the formation (Figure 2.3-7):

- the clay unit (UA) is the thickest (approximately 100 to 120 m), the most homogeneous and the richest in argillaceous minerals (more than 40% on average). It can be divided into 3 subunits (UA1, UA2 and UA3) with steady and gradual variations. Subunit UA2 is the stratigraphic level with the highest clay content; this is the level in which the Underground Research Laboratory's experiments are carried out;
- the transition unit (UT) forms the transition between the mainly argillaceous rocks of the UA and the rocks of the silty-carbonated unit (USC) with the highest carbonate contents (40% to 90%);

- the silty-carbonated unit (USC), 20 to 30 metres thick, has considerable vertical petrophysical variability linked with the lithological alternations (carbonaceous marls and siltites). It comprises levels with more contrasting and heterogeneous mineralogical composition.

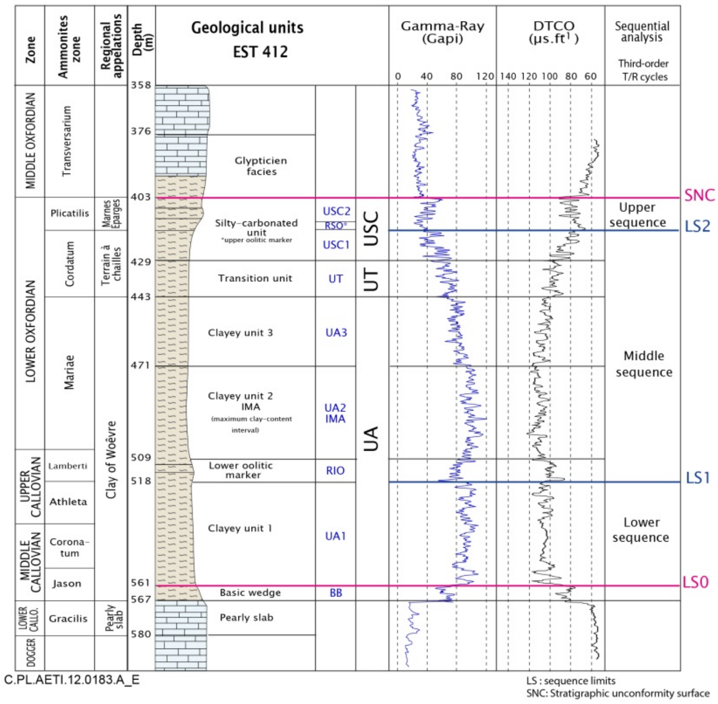

Figure 2.3-7 *Main geological units: argillaceous unit (UA), transition unit (UT) and silty-carbonated unit (USC). Geological limits of the Callovo-Oxfordian: LS0 (base of COX) and SNC (top of COX)*

Laterally, the Callovo-Oxfordian layer is generally organised in the same way over an area of more than 350 km2 according to the results from boreholes drilled within a 15 km radius of the Underground Research Laboratory. The constancy of these sequences gives evidence of the calm tectonic and sedimentary context during the period of deposition. Within the sector, this context is used to predict the lack of a gap in sedimentation of any size likely to disturb the continuity of the layer and the absence of sand lenses (turbidites) within the layer, given the distance from the sources of supply, particularly during the period of high sea level.

The macroscopic properties of transfers of mass (water, gas, solutes), and heat, and the mechanical properties of the Callovo-Oxfordian result from the structure of the porosity and the distribution of minerals within the clay rock. The permeability of the Callovo-Oxfordian is very low (in the region of a few 10^{-14} m/s with very low anisotropy). This very low permeability is explained by its argillaceous nature, fineness and very small pore diameter (0.05 microns on average), which severely restricts water circulation through the layer and obstructs the transfer of solutes by advection. Analysis of the distribution of certain chemical elements and their isotopes in the different minerals of the rock confirms that chemical elements are transported very slowly (taking several hundred thousand years to cross the layer), which is verified by diffusion tests on samples and in situ.

The containment capabilities of the Callovo-Oxfordian depend on its mineralogical composition: the most abundant of argillaceous minerals, of the "interstratified illite-smectite" type, have the particular characteristic of being made up of stacked flakes between which elements dissolved in water can be fixed in great quantities. This fixing capability further delays the migration of the elements into the Callovo-Oxfordian.

The mechanical properties of the host layer are linked to the mineralogical composition of the rock and its petrophysical properties (porosity, speeds), which give it relatively high resistance for a clay-based rock. Geomechanical tests and measurements have demonstrated that this clay rock is rigid, losing shape little and very slowly, which means that traditional excavation methods can be considered.

It has been possible to model the variability of the formation's properties (clay content, porosity, density, thermal conductivity, etc.) in the ZIRA using 3D seismic processing and all the borehole measurements. The values obtained have been compared with those measured from the samples. This comparison is used to check:

- the validity of vertical division into the geological units clearly identifiable in the ZIRA;
- the low lateral variability of the properties of clay rock in the ZIRA, the average values of which are very close to those determined from the samples, by logging in the boreholes or in situ in the Underground Research Laboratory.

The host formation: the Callovo-Oxfordian

This has simple structure in the form of a stack of contrasting major lithological units (alternating carbonates and clays) which are easily identifiable, flat, with little variation in thickness, and which are continuous on the scale of the transposition zone and the sector. It fits in perfectly with the general geometry of the deposits in the Paris basin.

Within these major units, the Callovo-Oxfordian is a predominantly clay layer with thickness varying from 130 m to 160 m, located at a depth of 500 m to 630 m. In the ZIRA, the Callovo-Oxfordian has mechanical characteristics appropriate for the construction of the disposal facility. Its thickness allows the siting of the underground facility, meeting the post-closure safety criteria (see DOS-AF). Compliance with the necessary undisturbed thickness of host rock to meet the post-closure safety requirements is built into the design of Cigeo (particularly the impact on the length of the structures).

Vertically, the layer is structured in sedimentary sequences, the boundaries of which are emphasised by thin carbonate deposits, which can be correlated over large distances. The central part of the Callovo-Oxfordian is the zone with the highest clay content (up to 60% clay). The top of the layer is characterised by carbonate enrichment. In the transposition zone and beyond, there is little lateral variation in lithology.

This formation is surrounded by two massive calcareous units (Dogger and Oxfordian limestone), without any outcrops in the transposition zone. The flatness of the outcropping layers in the transposition zone (Kimmeridgian marl in the valleys and Barrois limestone on the plateaus) determines their regular dips and differences in lithology, a characteristic relief of cuestas, with the areas of plateau grooved by deep valleys.

The petrophysical characteristics of the formations were acquired very early in geological history, either when they were deposited or just after, or during diagenetic phases, the most recent of which occurred in the tertiary period. The textural properties of the Callovo-Oxfordian were acquired during the early history of the formation. These determine the uniform characteristics of the whole of the formation.

2.3.5 Seismic activity

The Meuse/Haute-Marne site is part of a stable geological domain, characterised by extremely low seismic activity, as shown by seismic monitoring records (covering the whole of France since 1961, focusing on the Meuse/Haute-Marne sector since 2001) and historical records (earthquakes occurring and causing damage over the last 1,000 years).

In the Meuse/Haute-Marne sector, as in the whole north-western part of it, there is no historical earthquake epicentre and recorded seismicity is zero (Table 2.3-1). A very low level of seismic activity, not felt but recorded by seismographs, developed more than 30 km from the site in the easterly and south-easterly directions, away from the quasi-aseismic area of the central Paris basin. The closest region that has experienced seismic activity within historical times is more than 75 km from the site, at the western edge of the Vosges mountain range, and further away still in the Rhin graben.

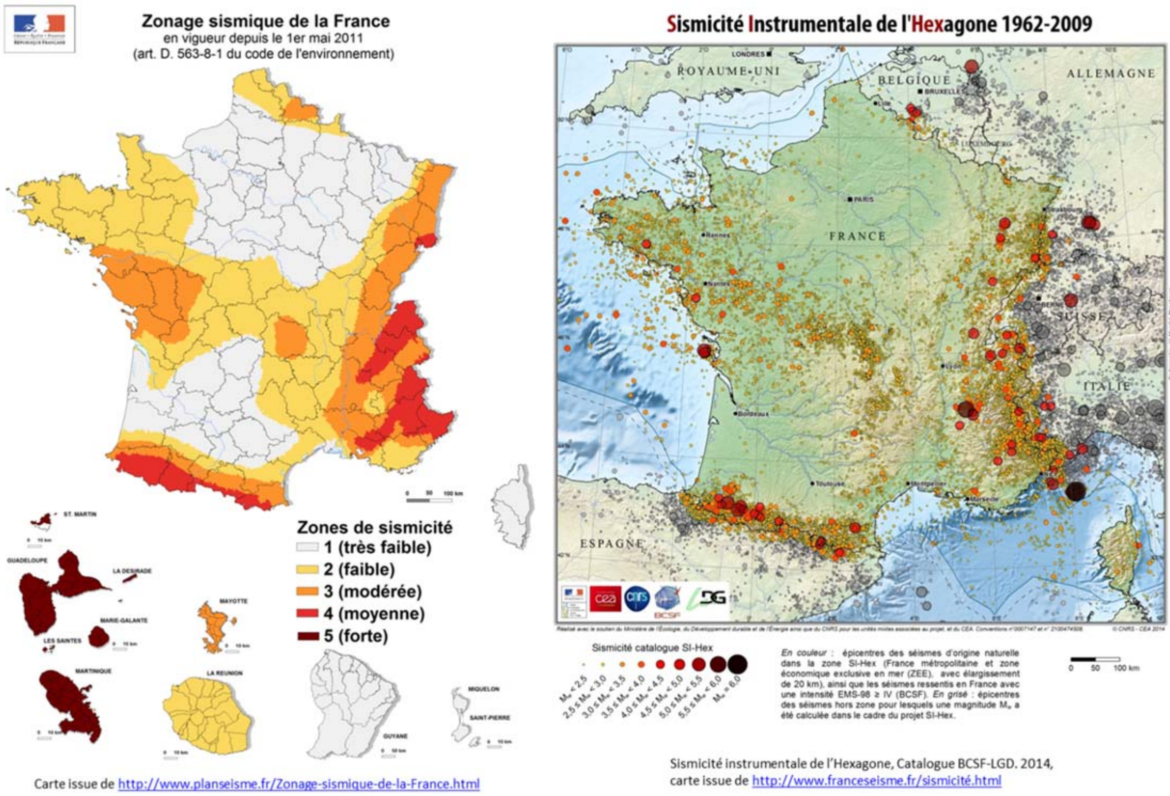

Figure 2.3-8 *Seismic zoning in France (left) and map of earthquakes recorded between 1962 and 2009 (right)*

2.3.5.1 Seismic uncertainty used for the design of the facilities

<u>On the surface</u>

At the site, possible seismic movement would be due to earthquakes with their epicentre a long way away.

On the seismic zoning map of France (Figure 2.3-8), which shows the probability of occurrence of earthquakes, the Meuse/Haute-Marne sector is located in a zone with seismic classification level 1, for which seismic uncertainty is described as "very low".

For conventional buildings with normal risk and an importance classification from I to IV (i.e. those for which the consequences of an earthquake are limited to the structure of the building itself and its occupants), the degree of movement from which construction rules must be applied, in accordance with Eurocode 8, is represented by an elastic response spectrum (defined by the order of 22 October 2010; NOR: DEVP1015475A). The reference maximum acceleration on rocky ground such as Barrois limestone not in the altered surface area is:

- 0.032×g for buildings in importance category I (formerly class A: buildings in which there is no human activity that requires a long stay);
- 0.04×g for buildings in importance category II (formerly class B under standard NF EN 1998-1 September 2005, such as offices and workshops accommodating a maximum of 300 people simultaneously, i.e. equivalent to 3600 m^2 net internal area, and less than 28 m high).

For surface nuclear buildings, the estimation of seismic uncertainty specified by BSR no. 2001-01 of 30 May 2006 "Determination of seismic risk for the safety of basic nuclear installations" is based on a deterministic approach using the known seismic level, established on the basis of the Maximum Historically Probable Earthquake (MHPE), from which the Safe Shutdown Earthquakes (SMSs) are deduced by enhancing the magnitudes by 0.5.

In order to meet an uncertainty objective associated with earthquakes with a minimum return period of 10,000 years, in accordance with the probabilistic approach recommended by the IRSN, the spectrum taken into account at present for the design of the Cigeo surface nuclear facility, is the median of the spectrum obtained using the probabilistic approach, considering a return period of 10,000 years for the earthquakes. The horizontal component of this spectrum is shown in the table below.

Table 2.3-1 Reference spectrum for the design of Cigeo facilities during the operating phase – Horizontal Component

Frequency (Hz)	0.50	1.00	1.11	1.25	1.43	1.67	2.00	2.50	3.33	5.00	10.00	34.00
Acceleration (g)	0.05	0.07	0.08	0.08	0.10	0.11	0.13	0.17	0.24	0.32	0.30	0.13

The spectrum of the vertical component is obtained by multiplying the accelerations of the horizontal component spectrum by a factor of 2/3 (Figure 2.3-9).

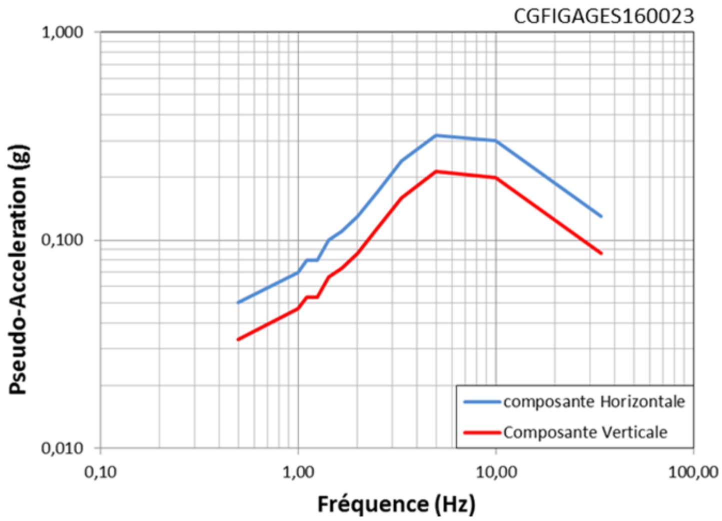

Figure 2.3-9 Spectrum used for the design of Cigeo facilities during the operating phase - horizontal and vertical components of seismic movements.

<u>At depth</u>

At present, in the absence of sufficient data on how seismic movements would develop as a function of depth in the specific geological context of the ZIRA, the same degrees of movement as at the surface are used, conservatively, for designing the necessary structures/equipment for operation of the underground facility and the surface-to-bottom connections.

For the design of the underground facility's structures necessary for the post-closure phase, installed during construction or operation, the MPPE spectrum with a return period of 100,000 years is used (Table 2.3-).

Table 2.3-2 Characteristics of the MPPE surface reference spectrum – horizontal component

Frequency (Hz)	0.1	0.3	1	5	9	34
Acceleration (g)	0.002	0.015	0.110	0.535	0.535	0.220

Seismic activity

As regards Cigeo's operation, it is not expected that the topography of the site will change or evolve, because external geodynamic phenomena due to erosion or tectonic movements affecting the surface environment will be negligible over this time scale.

Consequently, the data used for designing the surface facilities reflect the current geography and topography described above.

2.4 Hydrology and Hydrogeology

2.4.1 The hydrological surface network

Two waterways forming part of the Marne river basin pass through the ZIRA and ZIIS sector:

- the Orge to the west running alongside the ramp zone on the western side and about 2 km to the west of the shaft zone. The Orge is a tributary of the Saulx and itself has a small tributary on the right bank, called the Bureau;
- the Ormançon, running alongside the shaft zone to the east and about 3.2 km to the east of the ramp zone, is a tributary of the Ornain.

The source of these waterways is to the south of the sector in the Kimmeridgian marl formations. They do not flow permanently: their beds dry out in places in periods of low rainfall and in summer.

There are a few springs in the sector: at the head of the Orge and Ormançon basin on the Kimmeridgian marls and the Barrois limestone. The flow rates of springs in the Bureau and Orge valleys vary from a few litres per second to several tens of litres per second, or more than 100 l/s during flooding; the flow rates of springs in the Ornain valley generally vary from a few litres per second to a few tens of litres per second, except in summer dry spells.

The hydrographic network shows two water collection areas associated with water management upstream of the Paris region:

- the Marne reservoir (4800 ha, 349 million m^3) about 35 km away;
- the Aube reservoir (2320 ha, 170 million m^3) about 60 km away.

2.4.2 Structure and operation of the hydrogeological units overlying the Callovo-Oxfordian layer

The hydrogeological system around the Meuse/Haute Marne site and more specifically at the ZIRA is a multi-layer system comprising (Figure 2.4-1):

- the aquifers of the Barrois limestone, Oxfordian limestone, Dogger and Upper and Lower Trias. At the Meuse/Haute-Marne sector level, this aquifer system includes hydraulically active faults such as those of the Marne and Poisson, which run parallel to the major tectonic stresses and less draining faults acting more as hydraulic barriers such as the Gondrecourt North graben and the Joinville graben, which run NE-SW, perpendicular to the direction of the major tectonic stresses. There is a relatively active, hydraulically diffuse, fracture zone to the south-west of the ZIRA or the transposition zone (Figure 2.4-1);
- the semi-permeables of the Kimmeridgian marl, Callovo-Oxfordian clay rock, Lias clays and Middle Trias clays and evaporites.

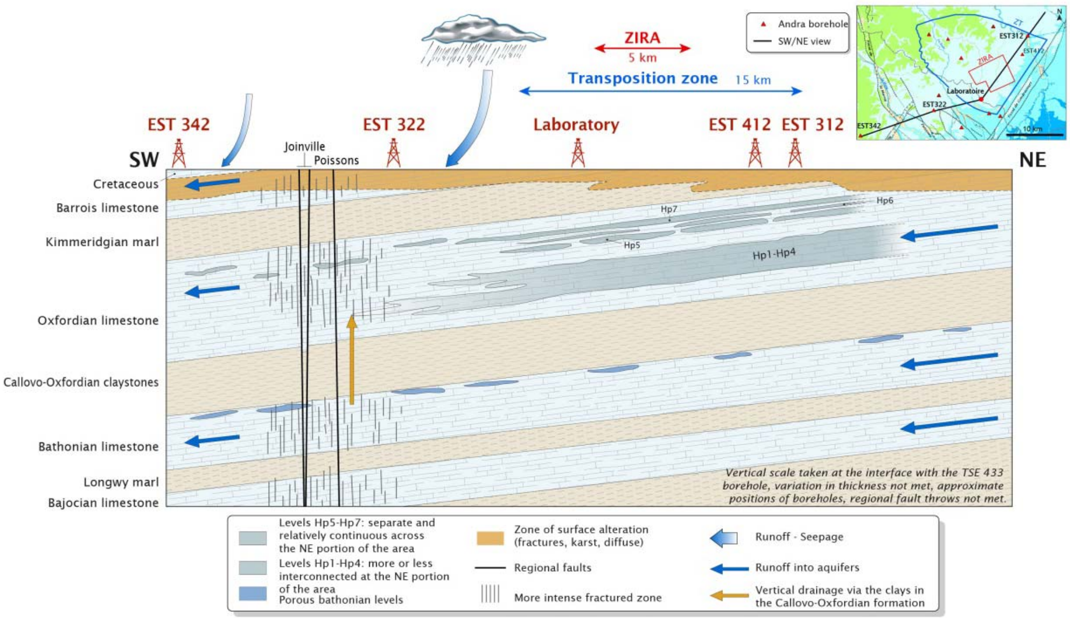

Figure 2.4-1 Representation of aquifer levels and their flows into the various geological formations in the Meuse/Haute-Marne sector

2.4.2.1 Surface aquifer system of the Barrois limestone

The Barrois limestone forms a multi-layer karstic aquifer system characterised by three aquifer formations (sub-lithographic limestone, Dommartin limestone and decayed limestone) separated by semi-permeable formations (Pierre Châline and Bure Oolite). The flows are organised in each of the three aquifer formations by the fracturing and a system of karst conduits running north-north-west. These aquifers are connected locally by vertical karst shafts.

Around the ZIRA, only the aquifers of the sub-lithographic limestones and the lower and middle Dommartin limestones are present. The Upper Dommartin limestones and the decayed limestones are found only at high points in the sector and form a desaturated zone. The sub-lithographic limestone aquifer becomes captive under the Pierre Châline, and the boreholes in the Ormançon and Orge valleys are artesian at high water levels.

In the more calcareous zones, permeability can be substantial or even high if the limestones are fractured and karstified. Three connected networks of karst conduits are developed in favour of fractures in the sub-lithographic limestone, the Dommartin limestone and the decayed limestone. Pumping tests in the boreholes at the Laboratory site indicate an average permeability of about 10^{-6} m/s representative of the sub-lithographic limestones, the only formation penetrated by these boreholes, or even a few 10^{-4} m/s as suggested by the BRGM's subsoil database, on the basis of results from pumping tests in 4 boreholes in the most karstified limestones.

The general flow of the two Barrois aquifers in the ZIRA (sub-lithographic limestones and lower Dommartin limestone) is northwards on the site (north-west to north of the ZT). This direction is dictated by topography and the surface water courses. The flow speeds are in the region of 10 km/year. Simulated current piezometry gives a hydraulic gradient of about 0.2% on the plateaus, while it can reach 1% around the valleys.

The main natural outlets of the Barrois limestone are the springs in the Saulx and Ornain valleys.

2.4.2.2 Aquifer system of the Kimmeridgian marls

This formation is predominantly marly (exogyra marls) and designates the unit overlying the Oxfordian limestone. The thickness of the formation increases slowly over the majority of the Transposition Zone (thickness varying on average between 100 and 110 m) except in the north-western part of the ZT where it increases more rapidly (120 m at EST441 and EST452).

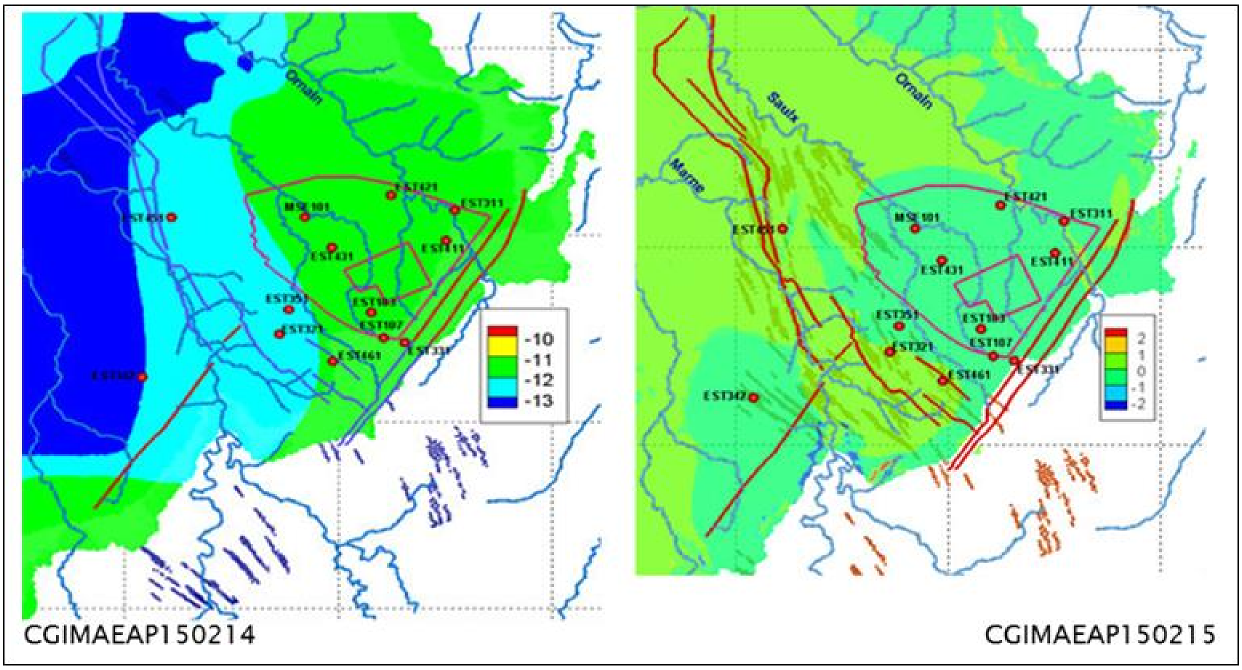

Figure 2.4-2 Permeability distributions in m/s of Kimmeridgian marl (left) and specific flows in m^3/m^2.yr exchanged with the Barrois limestone(right)

With permeabilities ranging from 10^{-11} m/s to 10^{-12} m/s around the transposition zone, the Kimmeridgian marl is semi-permeable with a downward vertical gradient due to the Barrois limestone and Oxfordian limestone aquifers, in the region of 0.34 m/m. In the ZIRA, the downward specific flow is less than 1 m^3/m^2 yr.

2.4.2.3 Structure and hydrogeological behaviour of the Oxfordian limestone

The middle and upper Oxfordian formations consist of: (i) limestone incorporating lithological variations demonstrated by the occurrence of porous horizons (HP) and (ii) a grey marly clay series.

The porous horizons are characterised by porosities and permeabilities ranging from 13% to 25% and 10^{-9} m/s to 10^{-7} m/s respectively.

Vertically, in the north-eastern part of the sector, the first 4 levels (HP1 to HP4) form the middle Oxfordian aquifer and the last three levels (HP5, HP6 and HP7) form the upper Oxfordian aquifer. In the north-eastern part of the ZT, the middle Oxfordian aquifer is separated from the upper Oxfordian aquifer by the semi-permeable layer formed by the marls of the "série grise" formation (Figure 2.4-3).

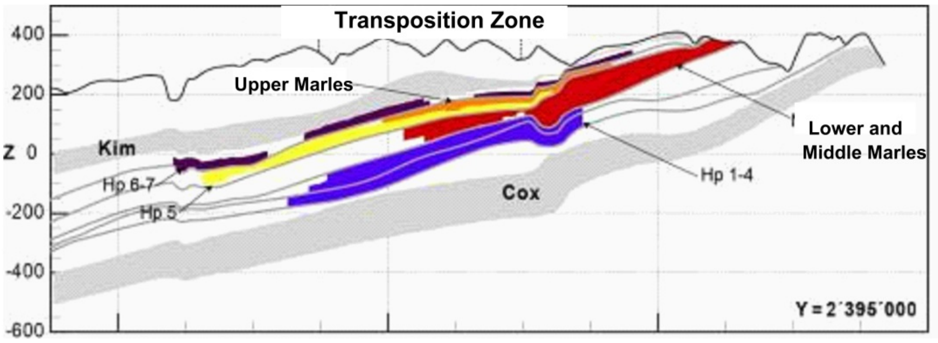

Figure 2.4-3 Vertical structure of the Oxfordian limestone aquifer system. The colours correspond to the different porous levels (violet, yellow, brown). The marls are shown in orange and red

In the south-western part of the ZT, the negligible thickness or absence of this semi-permeable layer means that all the Oxfordian limestone formations, including the porous horizons, form only a single aquifer generally with only a single flow field.

The transmissivities of the porous horizons are low, of the order of:

- 10^{-7} m^2/s for HP1 to HP4, 10^{-8} m^2/s for HP5, and 10^{-8} m^2/s to 10^{-7} m^2/s for HP6 and HP7 in the area where they are separated by the "série grise" formation;
- 10^{-8} m^2/s to 10^{-7} m^2/s where the HPs form a single aquifer.

The Oxfordian is recharged with water mainly by the outcrops to the east and the south-east of the sector. Water circulation in the sector is predominantly north-westerly, towards the centre of the basin.

The pore speeds in the region of 1 km per 100,000 years are confirmed by analysis of radioactive chemical elements (carbon-14, chlorine-36) in the water, based on a knowledge of their content in rainwater and their radioactive half-life, for a generally uniform and constant horizontal hydraulic head gradient of around 0.04 m/m.

The N150°E fault zone is fed directly by infiltration into the karst systems that have developed at the part of these faults that intersects the Oxfordian where it outcrops. The piezometry and the salinity there are different from those of the rest of the sector under study, depending on the connections within the fault system. The flows there are generally SE-NW.

Around the ZIRA, because of its low permeability in the region of 10^{-12} m/s and the fact that it is limited to the north-eastern part of the transposition zone, the "série grise" formation splits the Oxfordian aquifer into two parts, each with its own flow field:

- the upper Oxfordian aquifer has heads varying from 305 m to 280 m. The flows run towards the north and north-west with an average hydraulic gradient of 4%;
- the middle Oxfordian aquifer has heads varying from 295 m to 270 m, giving a horizontal gradient of 0.6%. The flows run towards the north-west with a uniform average hydraulic head gradient in the region of 4%.

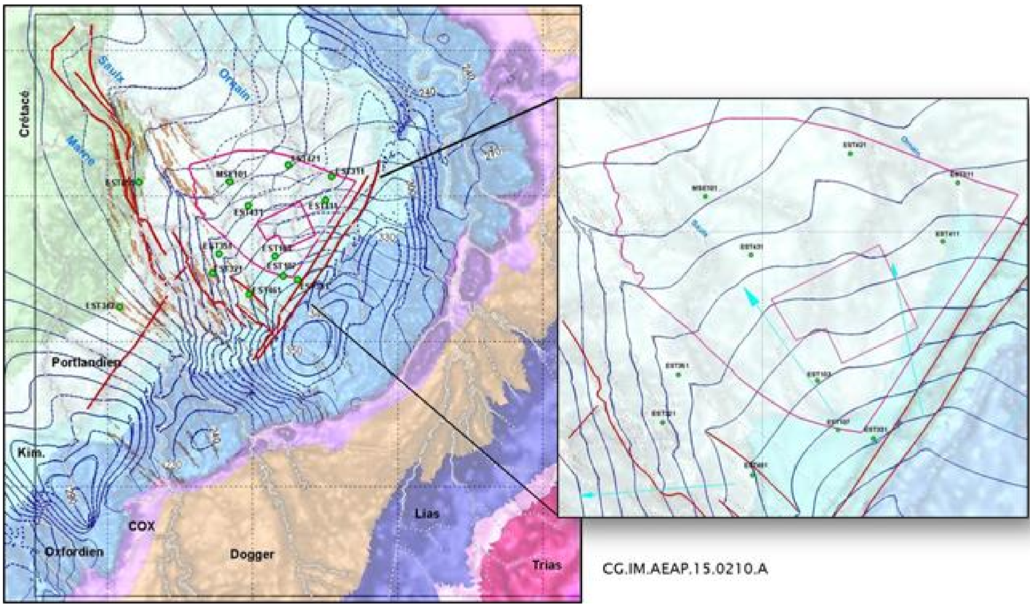

Figure 2.4-4 Simulated piezometries of the two Oxfordian limestone aquifers (upper Oxfordian aquifer on the left). Lateral piezometries of middle and upper Oxfordian limestone

2.5 Weather and climate

Western Europe has a temperate climate due to its geographical location in the middle latitudes and the influence of the sea. Its climate is modulated by regional and local effects closely associated with the properties of the surface (nature, altitude) and relationships with neighbouring regions (distance from coasts, proximity and slopes of mountain ranges, etc.).

The North-East of France has a continental climate transitioning to an oceanic climate in the West and an incursion into a mountain climate in the Vosges.

Meuse/Haute-Marne therefore has a transitional climate between the continental influence and the oceanic influence, affected by its topography characterised by an alternation of plateaus (altitude reaches 400 m) and cuestas (e.g. the Barrois plateau and the Côte des Bars).

The climate data shown below is based on measurements taken over 35 reference years from meteorological data acquired by observation station networks and entered into a database keeping a history of validated meteorological data:

- four Meteo France network reference weather stations situated close to the zone (less than 90 km away). These stations perform many automated and manual measurements and have a sufficiently long history to produce climate statistics;

- secondary stations, also with plenty of historical data (covering the period 1980-2014). They are used to add to these statistics and to report local effects. Although the variations in some parameters are dominated by large-scale factors, for others (wind, precipitation, fog, etc.), these large-scale influences are modulated by local factors (topography, type of surface, etc.).

2.5.1.1 Air temperature and relative humidity

The climate conditions of the air at the surface are characterised by:

- average annual relative humidity of about 80%;
- an average annual temperature of 11°C. Over the 35 reference years, average annual temperatures did not vary much (Table 2.5-) between 1980 and 2014; the increase in average temperature was in the region of a few tenths of degrees Celsius.

Table 2.5-1 Climate data (average annual temperature) from Meteo France stations in the sector during the period 1980-2014

Average annual temperature (°C)				
	Erneville-aux-Bois	Cirfontaines	Epinal	Saint-Dizier
Average	9.5	10.2	9.9	11.2
Standard deviation	0.7	0.7	0.7	0.7
Minimum	8.0	8.8	8.60	9.5
Maximum	10.9	11.4	11.1	12.5

The seasonal cycles are characterised by high temperatures in July and August and lower temperatures in January and February. The amplitude of the annual cycle is approximately 17°C. Negative average minimum temperatures were recorded at Erneville and Cirfontaines in January and February.

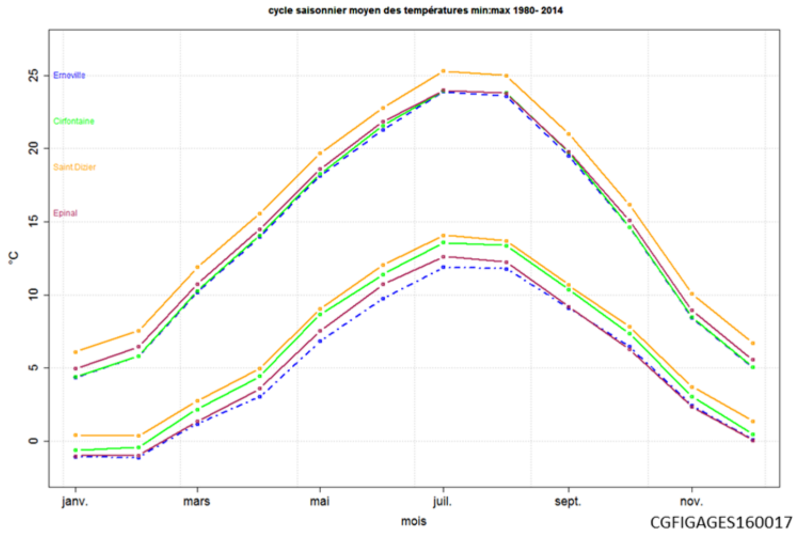

Figure 2.5-1 Average annual cycles of maximum and minimum temperatures during the period 1980-2014 for the stations at Erneville aux Bois, Cirfontaines, Epinal and Saint Dizier

The extreme temperatures (reached at Saint-Dizier and Epinal) are:

- 39°C in July 1983 and 40°C in August 2003; this peak was above 35°C for more than eight consecutive hours. According to Meteo France this constitutes a "heatwave [that] is far in excess of any experienced since 1873 in terms of its intensity and duration, both for maximum and average temperatures". The temperature of 40°C is taken as the maximum short-term temperature (24 h). To take account of any potential climate change caused by human activity over the period of operation and to cover uncertainties concerning the instantaneous temperature peak, this maximum temperature is conventionally increased by 5°C and the maximum instantaneous temperature ascertained from hundred-year values over 6 hours is taken conservatively as 45°C;
- -20.5°C in January 1985 and -22.5°C in February 1956 at Saint-Dizier. The temperature of -20°C is taken as the minimum short-term temperature (24 h). To take account of any potential climate change caused by human activity over the period of operation and to cover uncertainties concerning the instantaneous minimum temperature, this temperature is conventionally decreased by 5°C and the instantaneous minimum temperature ascertained from hundred-year values over 6 hours is taken as -25°C as a bounding value.

2.5.2 Precipitation (rain and snow)

The precipitation characteristics are as follows:

- the annual cumulative precipitation is an average of about 900 mm (1073 mm for stations close to the zone, 837 mm at Saint-Dizier and 947 mm at Epinal, 916mm at Cirfontaines);
- extremes of precipitation have occurred:
  - ✓ in 2003, a year of drought and heatwaves, precipitation of 633 mm at all eleven stations in the sector;
  - ✓ in 2001, total precipitation of 1536 mm at Grand and an average of 1374 mm at all stations close to the zone.
- autumn and winter are the wet seasons and the two months with greatest rainfall are December and January, with precipitation between 100 and 135 mm per month;
- spring is the driest season and the two driest months are April and June, with precipitation between 60 and 90 mm per month;

The data used for design of the facility comes from the Cirfontaines weather station, which is closest to the surface nuclear facilities (Table 2.5- in red).

Table 2.5-2 Minimum, average and maximum total annual rainfall over the period 1980-2014 at the Meteo France stations near the site

	Precipitation (mm)				
	Erneville	Cirfontaines	Gondrecourt	Epinal	Saint-Dizier
Minimum	691	633	712	645	562
Average	1050	916	1033	947	837
Maximum	1378	1175	1294	1207	1094

In winter there are regular snowfalls. These represent between 8 and 10% of annual precipitation covering an average of about 25 to 30 days per year. Snow can fall between November and April with an average of 7.5 days per month in February.

The snowfall load used for design purposes is 35 daN/m² under normal conditions and 60 daN/m² under extreme conditions.

2.5.2.1 Storms and lightning

Storms mainly occur between May and September with an average of 3 to 5 days of storms during this period, which is low overall in relation to the French average (11.54 days). The number of days of storms per year within a 5 km radius of the commune of Bure is 11 on average (1999-2008 period) with an average of 1.44 lightning strikes per year and per km².

The design of the facilities as regards lightning is based on:

- the general standards for lightning protection (NF EN 62305);
- the standards for protection of structures and open areas against lightning (NFC 17-100 and NFC 17-102);
- the electrical design and construction rules (NFC 15-100);
- the UTE C 15-443 Guide to choosing and installing lightning protection.

2.5.2.2 Winds

Within the sector, wind levels generally vary from very low to moderate (nearly 70% of occurrences). Average wind speed is about 10 km/h. The winds fall into two main categories:

- south-westerly winds (between 180° and 260°E), which account for about 30% of occurrences and tend to be fairly strong (15 km/h on average);
- less common easterly winds (between 60 and 120°E), accounting for about 20% of cases, which tend not to be as strong: an average of 10 km/h with very few winds above 20 km/h.

Strong winds, above 40 km/h, accounting for less than 1%.

The maximum gust of wind recorded at St Dizier since 1 January 1981 was nearly 160 km/h on 26/12/1999, reaching level EF1 on the Fujita scale. On the same day, record winds were also measured at the Epinal and Nancy stations with maximum gusts of 133 km/h and 144 km/h respectively.

The following data are used for design purposes:

- the wind compass for the Saint-Dizier station (Figure 2.5-2), weighted to take account of the effects of the local topography (plateau and valley effects);
- a wind level corresponding to an EF2 level tornado (gusts of between 50 and 60 m/s).

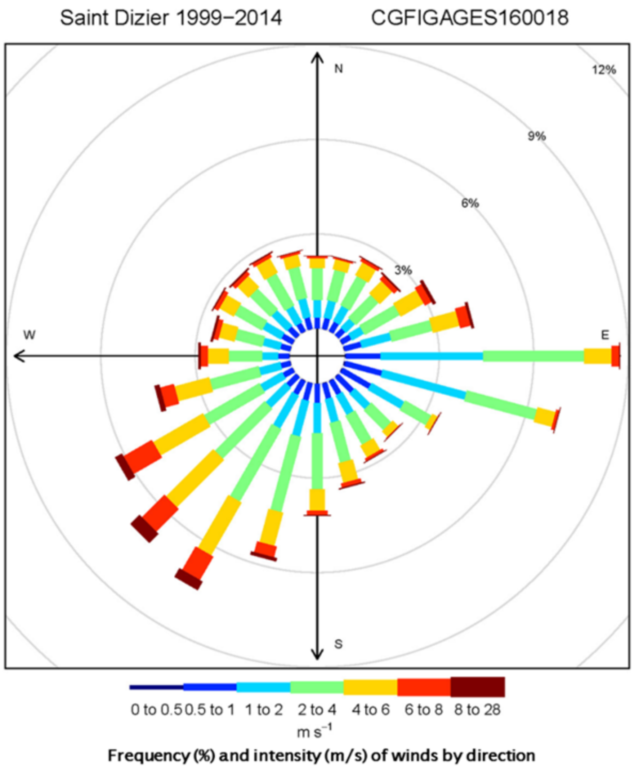

Figure 2.5-2 Wind compass for Saint-Dizier for the period 1999-2014

2.5.3 Other phenomena

2.5.4 Landslides and rockfalls

No areas with a risk of landslides or sinkholes have been identified in the environment of the zones where surface facilities are located.

Muck piles are stored on the surface with banks that will be designed and dimensioned to prevent landslides.

2.5.4.1 Swells and floods

The surface facilities are located outside zones with a flood or high water risk, and no Flood Risk Prevention Plan is listed in the environment of the zones where surface facilities are located.

Changes in the transfer of rainwater to the subsoil due to the presence of surface facilities (waterproofing around the muck piles, modification of routes and quantities of runoff water, etc.) are taken into account in the design of the facilities, particularly in the event of very heavy rainfall.

Weather and climate

The Meuse/Haute-Marne sector has a transitional climate between the continental influence and the oceanic influence, affected by its topography characterised by an alternation of plateaus (altitude up to 400 m) and cuestas (e.g. Barrois plateau and Côte des Bars).

The annual average relative humidity of the air at the surface is in the region of 80%, and the annual average temperature is about 11°C; the amplitude of the annual climate cycle is about 17°C, characterised by high temperatures in July and August and low temperatures in January and February. The total annual rainfall is about 900 mm on average.

The following data are used for design purposes:

- temperature extremes of +45°C and -25°C including a conventional margin of 5°C to take account of any climate change;
- annual rainfall corresponding to measurements at the Cirfontaines station [600 – 1200 mm];
- the number of days of storms per year within a 5 km radius of Bure estimated at 11 days (1999-2008 period) with an average of 1.44 lightning strikes per year and per km²;
- snowfall of 35 daN/m² under normal conditions and 60 daN/m² under extreme conditions;
- the wind compass of the Saint-Dizier station, weighted to take account of the effects of the local topography (plateau and valley effects);
- a wind level corresponding to an EF2 level tornado (gusts of between 50 and 60 m/s).

2.6 Natural resources and foodstuffs

2.6.1 Mineral and hydrocarbon resources

Over the whole of the transposition zone, including the ZIRA, and in general in the sector:

- at present there is no operating Barrois limestone quarry anywhere in the zone (BRGM, 2015) to meet local needs for construction stone, aggregate or hardcore, according to the BRGM Banque du Sous-Sol (BSS). There are no alluvial material resources (sand, gravel, etc.), either proven or previously worked, due to the absence of a substantial alluvial plain;
- there is no mining activity anywhere on the sedimentary cover as it does not contain any economically exploitable mineral;
- no potentially exploitable coal resources appear in the geological data. Coal formations develop about 40 km east of the sector, in the Westphalian formations not present within the sector;
- the geological conditions are not conducive to the potential presence of conventional hydrocarbons. The 3D seismic reflection survey of the ZIRA carried out by Andra in 2010 did not detect any structure likely to constitute a hydrocarbon reservoir (Andra, 2012). The nearest hydrocarbon deposits are at Forcelles (oil) in Meurthe et Moselle, about 54 km east-south-east and at Trois-Fontaines (gas) near St Dizier, 39 km to the north-west. These two deposits, which are no longer worked, are structural deposits located in the middle to upper Triassic strata (Andra, 2012; Delmas et al. 2002).
- there is practically no probability of potential non-conventional hydrocarbon resources. There is no Westphalian parent rock within the ZIRA; the western limit of the Westphalian is more than 10 km to the north and north-east of the zone. The Stephanian parent rock present within the ZIRA has a very low content of potential parent rock, coal and schists containing organic matter.

2.6.2 Geothermal resources

The data acquired in the sector by Andra, particularly from borehole EST433 drilled to a depth of about 2000 m, one of the scientific objectives of which was to assess local geothermal characteristics, showed that these characteristics (geothermal gradient and hydrodynamic characteristics of the upper aquifer of the Triassic Bunter sandstone) were common and were not exceptional compared with elsewhere in the Paris basin. The geothermal gradient is about 3°C/100 m, which is within the national average, and the temperature of the aquifer water from the Bunter sandstone (between 1860 and 1890 m deep) is 66°C with a very high salinity of 180 g/l.

2.6.3 Water resources

At present in the sector under study, the surface aquifer formation of the Barrois limestone outcropping in the ZIRA is an exploitable water resource. The limestone forms a karstic aquifer characterised by fast circulation in response to rapid rainwater infiltration reactions and underground channels that probably also have a rapid flow. This rapid flow capacity greatly reduces the water storage capacity of this aquifer. The exploited water resources originating in the Barrois limestones are located mainly along the Orge, Saulx and Ornain watercourses.

The captive and deep Oxfordian and Dogger aquifers are not exploited in the sector, because of the salinity of their water and their low flow rates.

2.7 Other activities around the site

2.7.1 Industrial activities

The region is not highly industrialised.

Environmentally regulated facilities (or ICPEs) present within a radius of 50 km around the site are:

- SODETAL SAS (manufacture of metal products): ICPE classified AS (authorisation with easements), the off-site emergency plan (PPI) radius of which does not include the Cigeo project site. This ICPE is in Tronville-en-Barrois (Meuse), 25 kilometres from the site;
- RHOVYL (manufacture of artificial and synthetic fibres): ICPE classified Low Threshold at Tronville-en-Barrois (Meuse), 25 km north of the site;
- FERRO France (manufacture of enamels for metals, glass and ceramics): ICPE classified Low Threshold at Saint-Dizier (Haute-Marne), 30 km north-west of the site;
- STOROPACK France (manufacture of rubber and plastic products): ICPE classified Low Threshold at Nully (Haute-Marne), 40 km south-west of the site;
- HUNSTMAN SURFACES SCIENCES FRANCE (manufacture of soaps, detergents and maintenance products) ICPE classified AS (authorisation with easements) at Han-sur-Meuse (Meuse), about 40 km north of the site;
- the Syndièse[39] platform is at the north-west of Saudron, about 2 km from the ramp zone and 4.5 km from the shaft zone. This is an ICPE subject to declaration for production of biofuel.

There are two wind farms about 5 km from the site, located respectively to the north-east and the south-west of the zone.

[39] The site for the Syndièse project was chosen in full knowledge of the potential siting of the Cigeo project.

2.7.2 Land communication routes

This includes communication channels including roads, railways, waterways and networks (electricity lines and gas pipes).

2.7.2.1 Networks

The main networks identified around the site are:

- underground gas and fuel pipes. In order to supply the site, eight natural gas boilers will be installed, distributed over both zones (ramp and shaft). There are several options for connection to the existing natural gas network, currently being studied:
  - ✓ via the Antenne de Joinville to the west,
  - ✓ via the Artère de l'Est to the north,
  - ✓ via the Réseau national des Marches du Nord-Est to the east,
  - ✓ via the DN200 pipeline in Trois-Fontaines;
- electricity lines: one very high voltage line that passes about 300 m to the north of the ramp zone and 2 km to the south of the shaft zone. It will supply electricity to an RTE substation, from which two underground lines will serve both surface sites.

2.7.2.2 Communication channels

Cigeo is not near any major roads such as motorways or national roads carrying large amounts of traffic, or routes used for the transportation of hazardous materials.

The following roads are located close to the facilities:

- departmental road D960 (connecting the communes of Saudron and Mandres-en-Barrois in particular): this road currently passes through the ramp zone. A bypass to the north of the ramp zone is planned as part of the Cigeo project, with a minimum distance of about 650 m;
- departmental road D175 to the west of the ramp zone (connecting the communes of Saudron and Gillaumé) at a distance of about 500 m.

Currently, the volume of traffic on these two roads is fairly small. However, this will need to be reassessed later on in order to take account of the potential impact of the presence of the project installations.

The closest railways to the project are:

- the line between Saint-Dizier and Chaumont via Joinville, more than 20 km to the west of the ramp zone;
- the line between Bar-le-Duc and Commercy, nearly 20 km to the north of the ramp zone;

The freight line (single track, not electrified) between Nançois/Tronville station and Gondrecourt-le-Château, running along the Ornain valley just over 10 km to the north-east of the ramp zone.

A new railway line is to be created as part of the Cigeo project, between the existing line at Gondrecourt-le-Château and the ramp zone, particularly for use in routing waste packages from producers to the facilities. This line will also be used by Cigeo to carry other equipment or materials (construction sites) and to reduce road traffic. The railway terminal is adjacent to the surface nuclear facility in the ramp zone, to the south of it.

As regards waterways, two navigable canals running north to south are within a 20 km radius: to the east, the Marne-Rhine canal and to the west, the Champagne-Burgundy canal.

2.7.3 Air communication routes

The airports currently sited within a 30 km radius of the zone are:

- Joinville-Mussey, about 15 km to the south-west;
- Saint-Dizier, located about 20 km to the west;
- Bar le Duc, located about 25 km to the north;
- Neufchâteau, located about 30 km to the east.

There is also a heliport in the ramp zone outside the INB perimeter. The landing platform is designed mainly to receive emergency medical assistance (SAMU) helicopters and, in an emergency, to be used by the administrative authorities (police, army, prefect, etc.). It can take only one helicopter.

As regards commercial aviation, the nearest airports are Epinal (50 km) and Nancy-Essey (55 km).

An aviation map of the Cigeo area is provided in the appendix.

Table 2.7-1 Aviation around Cigeo

Airport	Type of aviation	Traffic (in movements)
Joinville	integrated	No information available, conservative value of 5000 movements applied
Saint Dizier	military	14124 movements including 1767 for civil aviation in 2007
	integrated	
Bar le Duc	integrated	No information available[40]
Neufchâteau	integrated	No information available[40]

There is an air corridor above the zone "UL161". This is for upper airspace navigation, but the route used infrequently on a conditional basis because it interferes with military activities, which take priority.

There is also a TACAN (TACtical Air Navigation) route "R11" above FL195 level, which can only be used by military aircraft.

As shown in the figure below, several regulated zones are identified:

- zone R27: regulated zone protecting movements of military aircraft around St-Dizier airport, and military air traffic at altitude;
- zone R98B: regulated zone protecting military air traffic around Nancy-Ochey air base and protecting aircraft departures/arrivals to/from the West from/to Metz-Nancy-Lorraine and Nancy-Essey;
- zone R45N5: regulated zone used for high-speed training at very low altitude

[40] To calculate the probability of an aircraft crash affecting Cigeo, in application of the chosen methodology, only traffic data for airports within a 20 km radius of the site are necessary. For airports more than 20 km from Cigeo, no traffic value was therefore used.

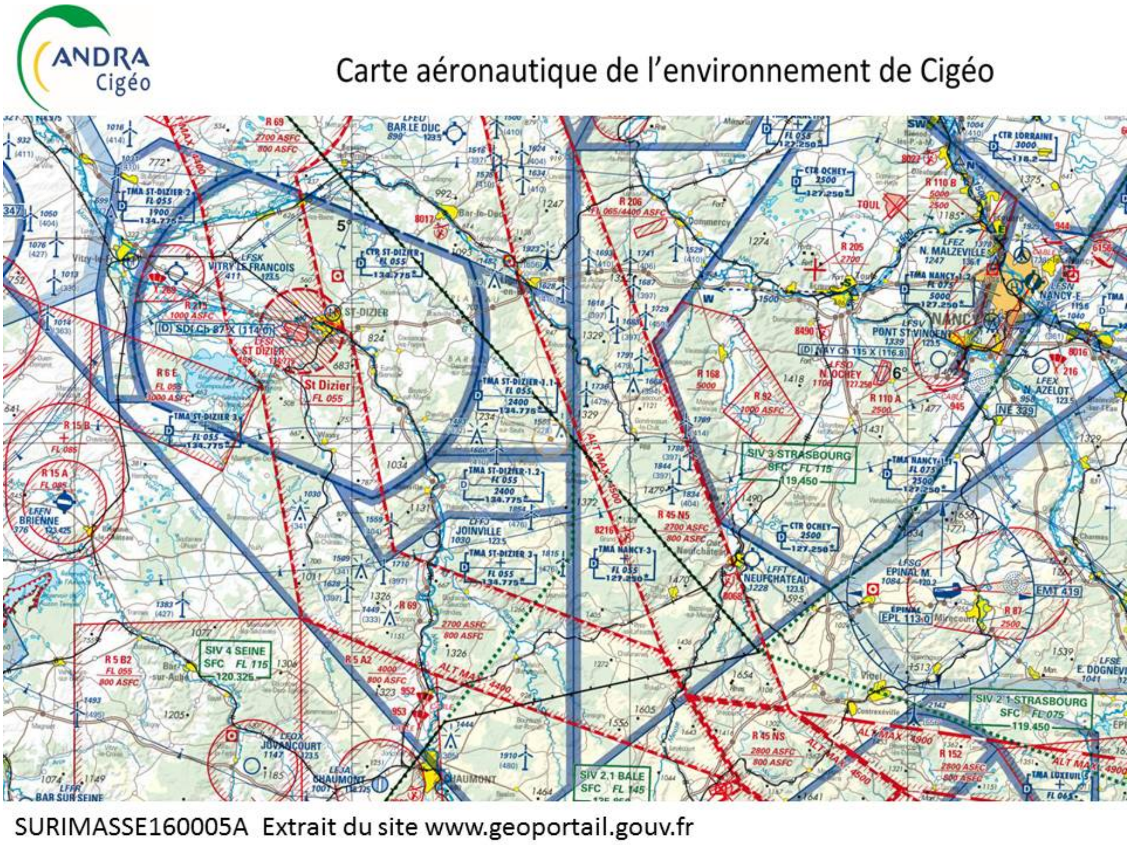

Figure 2.7-1 Aviation map of Cigeo environment

The whole of the zone is located:

- under zone TSA 20 A dedicated to combat training above FL195 level;
- under regulated zone R21 dedicated to combat training between levels FL115 and FL195.

3

Facilities and Equipment

3.1 Ramp zone surface nuclear facilities

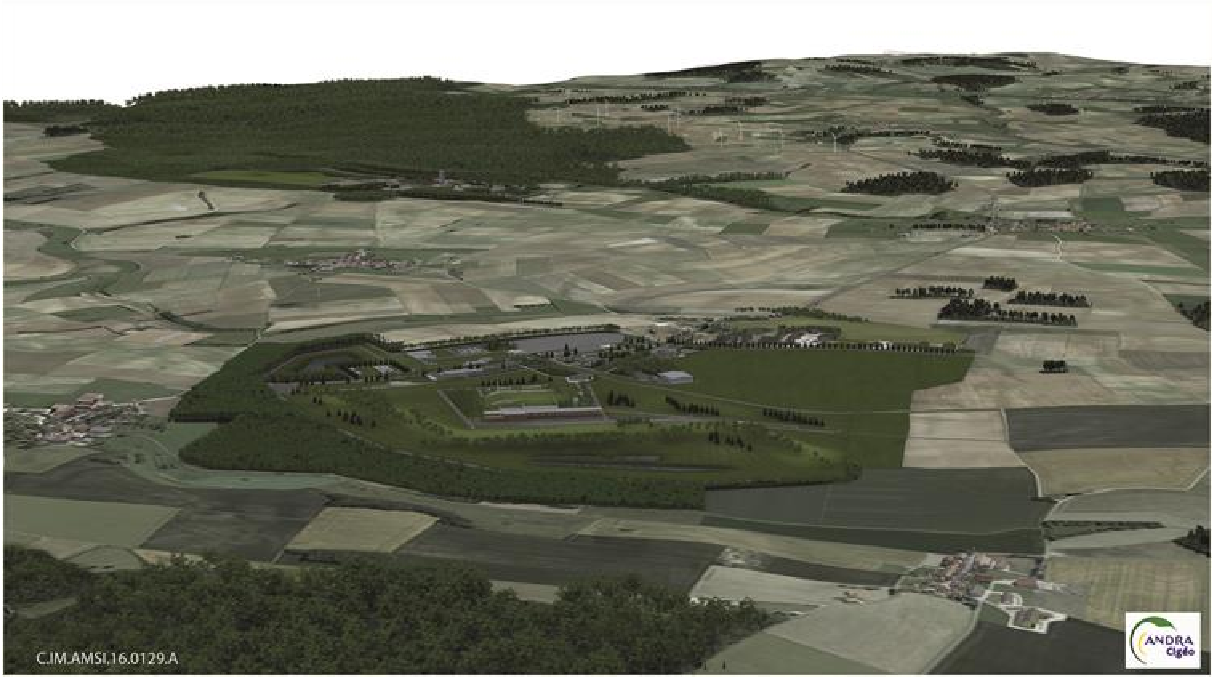

Figure 3.1-1 "Ramp zone" geometric perimeter

The "ramp zone" comprises two surface nuclear facilities EP1 and EP2.

The design of EP1 adopts a partially buried building solution, with bunding around the parts emerging from the ground. This is the best solution for managing the interfaces with the nuclear process, with the container arrival area to the upstream side and with the partially-buried ramp leading to the repository on the downstream side, having a more favourable impact on the landscape than a surface facility.

The EP2 facility is not covered in the description of the main process of the surface nuclear facilities below.

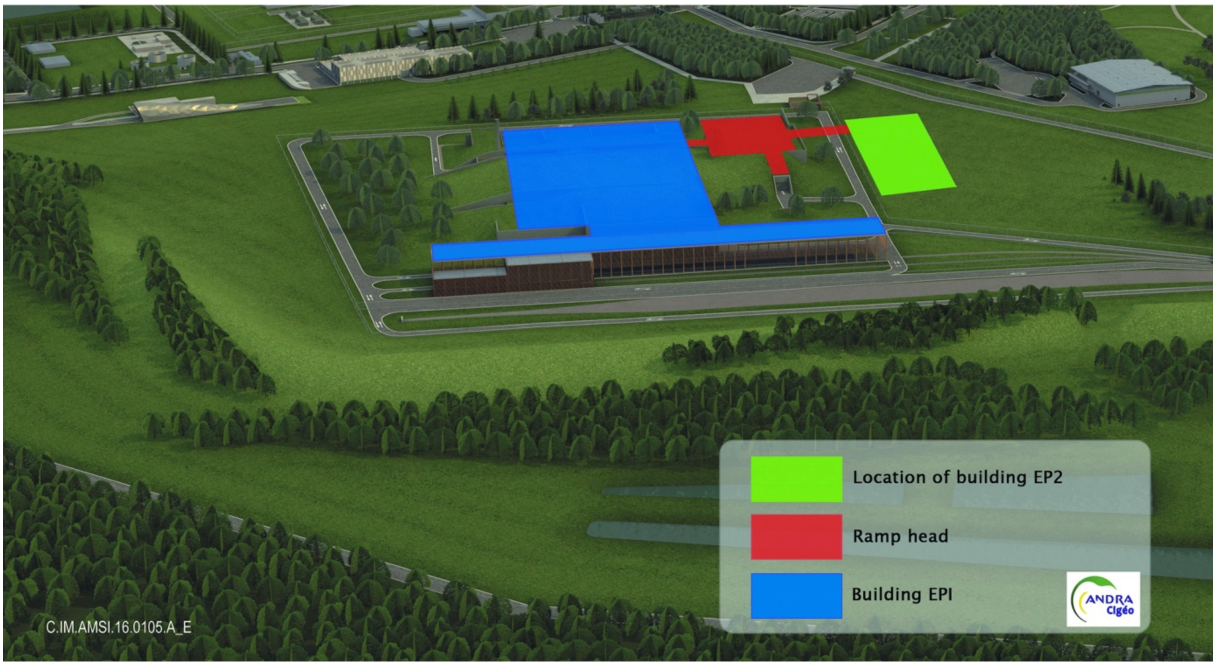

Figure 3.1-2 Nuclear facilities in the "ramp zone"

The EP2 facility scheduled to be commissioned following EP1 in around 2070 is not specifically described in this document.

It is similar to EP1 in terms of the functions and risks.

It shall be constructed as part of a closed-off site connected to the Eastern part of the layout below. Co-activity will therefore be limited.

3.2 Functions and presentation of surface nuclear facilities

The buildings of the "ramp" zone fulfil the following functions:

- reception of waste packages in transport containers;
- unloading of primary waste packages (CP);
- forming the disposal packages (CS) for the waste packages placed inside disposal containers (see solutions no. 1 and no. 2 presented in the section covering packages[41]);
- transferring the disposal packages to the cask loading area;
- placing the disposal packages in casks;
- performing inspections;
- managing secondary waste and effluent;
- handling of disposal packages in accordance with the "retrievability" principle (see retrieval operating scenario presented in the DORec).

[41] It should be remembered that, in the case of solution no. 3 relating to the direct disposal of packages arriving at Cigeo in the disposal cells without containerisation, the waste package is also the *de facto* disposal package

Note: The option of not placing certain ILW-LL primary packages in disposal containers and disposing of them directly in the disposal cells requires adaptations to be made which will be specified between now and the construction licence application.

The surface buildings within the ramp zone consist of:

- **A main building comprising:**
  - ✓ vertical or horizontal transport container unloading bays;
  - ✓ vertical transport container preparation and unloading rooms;
  - ✓ primary package conditioning in disposal packages and package transfer areas;
  - ✓ container and disposal package buffer zones;
  - ✓ utility /ancillary rooms for ensuring the operation of the process and its support facilities;
  - ✓ disposal package cask loading and cask storage areas.
- **A waste package ramp head building comprising:**
  - ✓ connecting drifts to the main building;
  - ✓ ramp transfer system upper station;
  - ✓ ramp transfer system maintenance pit;
  - ✓ machine rooms;
  - ✓ utility /ancillary rooms for ensuring the operation of this building.
- **A sample test inspection, deviation management and waste effluent building comprising:**
  - ✓ control cells;
  - ✓ non-complying package reconditioning cells;
  - ✓ radioactive waste and effluent treatment rooms;
  - ✓ utility /ancillary rooms for ensuring the operation of this building.

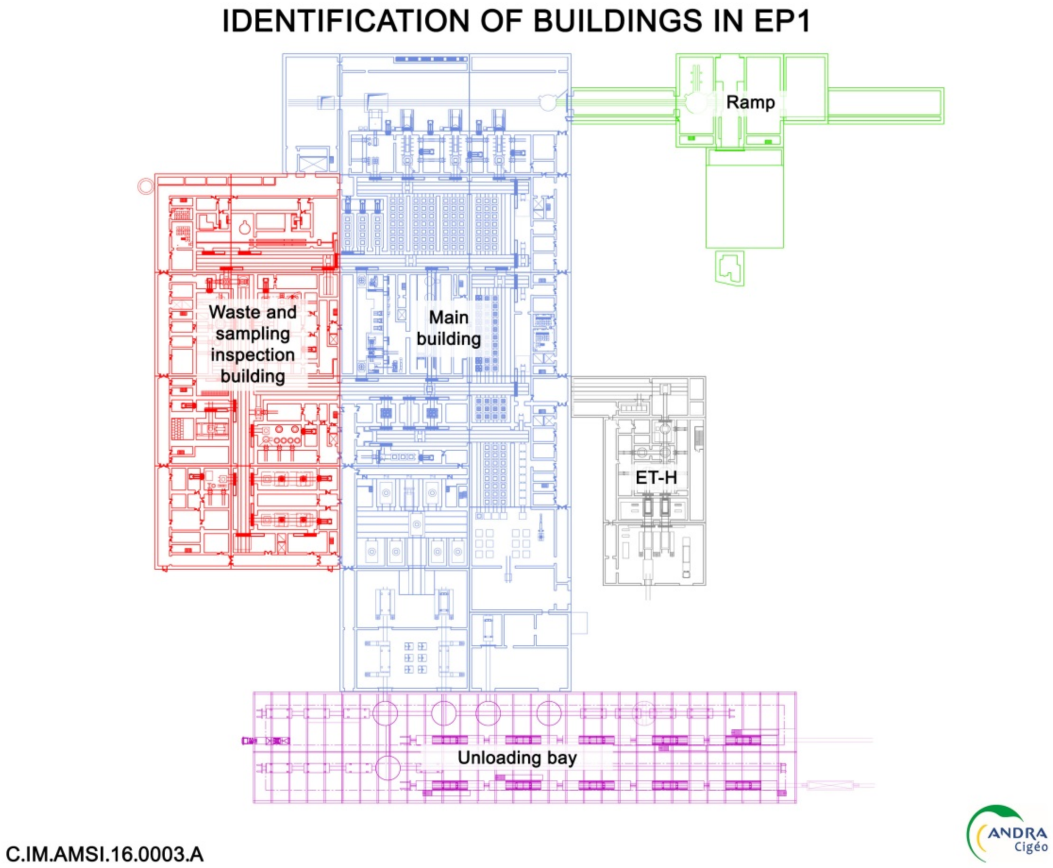

Figure 3.2-1 Buildings forming EP1

The deployment of the EP1 facility will be a gradual process, and adapted to suit the functional and capacity requirements associated with the delivery schedule, and as near as possible to the dates on which they occur.

EP1 can therefore adapt to changes in the "PIGD" Industrial Waste Package Management Programme (reception schedule, reception flows, date of partial closure) without modifying existing infrastructure or equipment and without constructing new buildings. This installation provides the flexibility, in particular, to increase the rate of use as required (e.g. transition from 2-shift operation to 3-shift (24hrs a day) or 5-shift (24h a day 7 days a week)

At the Cigeo start-up (once authorised to receive packages), the facility will include the HLW0 and ILW-LL package conditioning process lines, together with an HLW and an ILW-LL line. The HLW conditioning line will be reconfigured as an ILW-LL line after disposal of the HLW0 packages (in around 2040).

3.3 General description of the surface process

3.3.1 Organisation by process unit

The Cigeo is broken down into functional blocks that are functionally homogeneous and consistent in terms of safety within a given block.

The process is therefore broken-down into “process units” fulfilling the following functions:

- process unit F1 – “Unloading convoys”;
- process unit F2 – “Placing primary packages in containers”;
- process unit F3 – “Conditioning/deconditioning of disposal packages”;
- process unit F4 – “Loading disposal packages into casks”;
- process unit F5 – “Sampling control”;
- process unit F6 – “Management of nuclear and conventional secondary waste”;
- process unit F7 – “Process support”.

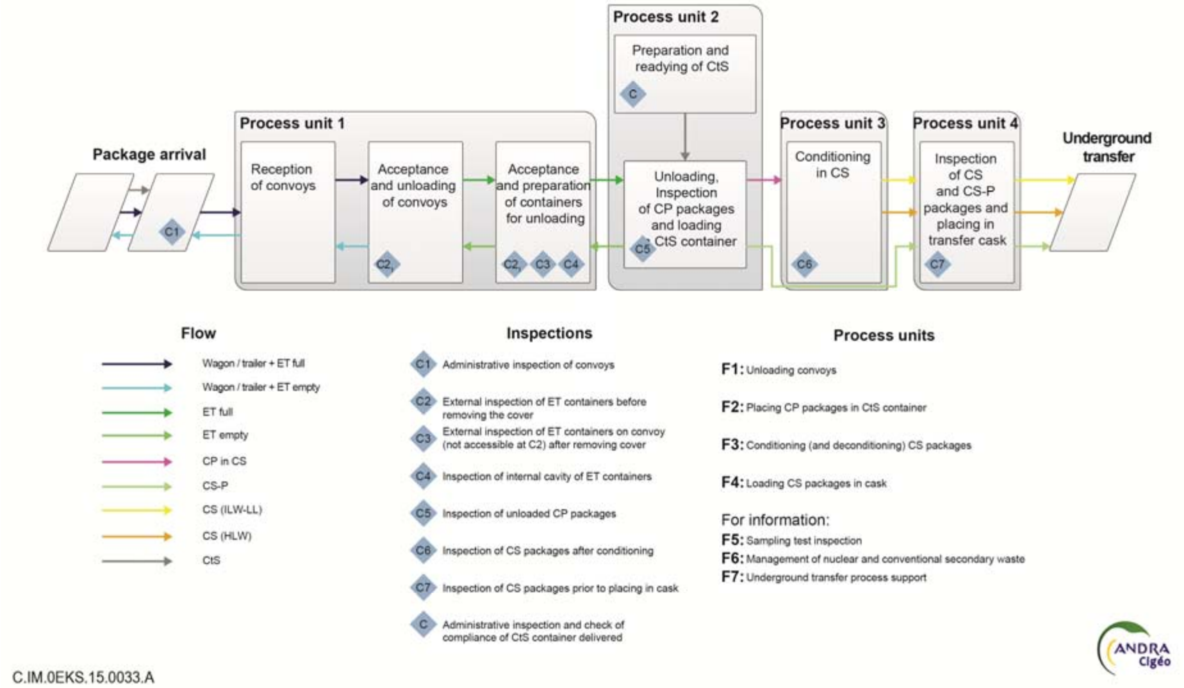

Figure 3.3-1 Summary diagram of main functions necessary for package disposal

All the above process units are arranged in such a way as to minimise the package handling/transfer times and limit, as far as possible the risk of dropping a transport container or a waste package. These process units are therefore distributed within the different buildings as follows:

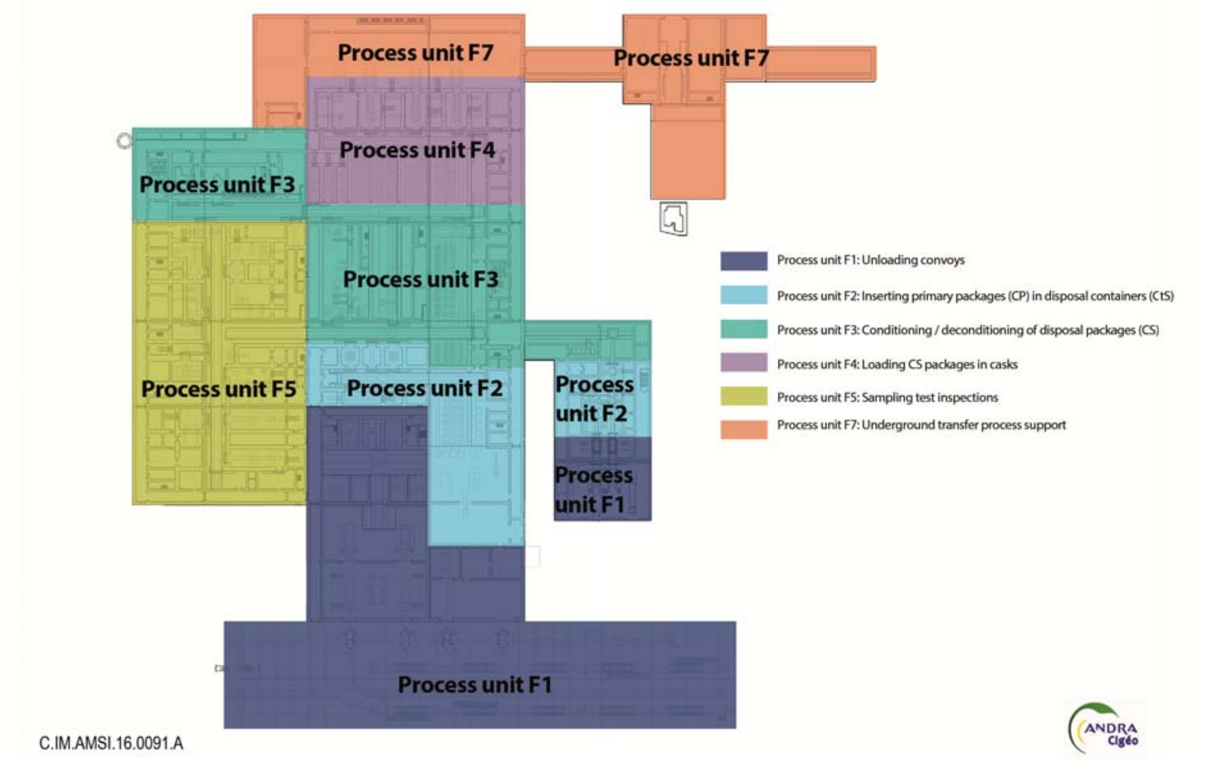

Figure 3.3-2 Distribution of process units within EP1

3.3.2 Process unit F1: Unloading convoys (transport containers and primary packages)

The transport containers arrive at Cigeo from the different waste producers' sites by either road or rail.

3.3.2.1 Road convoys

Upon receiving authorization, the road convoys enter into the perimeter of the basic nuclear installation where they are then parked. Upon successfully passing all inspections, the convoy enters a covered parking area.

Road convoys of "ET-H" type horizontally unloading transport containers are directly unloaded in the unloading building.

3.3.2.2 Railway convoys

After passing the guardhouse at the outer boundary of the basic nuclear installation, the train is parked at the railway terminal. The administrative inspection is conducted at the railway terminal. The half-convoy is then positioned beneath the convoy unloading bay ready for unloading. The wagons can be brought under the unloading bay by half-convoy via a special track.

Convoys of disposal containers also pass a gatehouse, and are transferred, one wagon at a time, into the disposal container unloading bay.

The transport containers are unloaded from the wagons by means of a gantry crane which sets the containers down on an adaptable frame.

In the event that contamination is detected on a container during inspection, a decontamination operation is performed on the wagon or in the non-complying container processing cell.

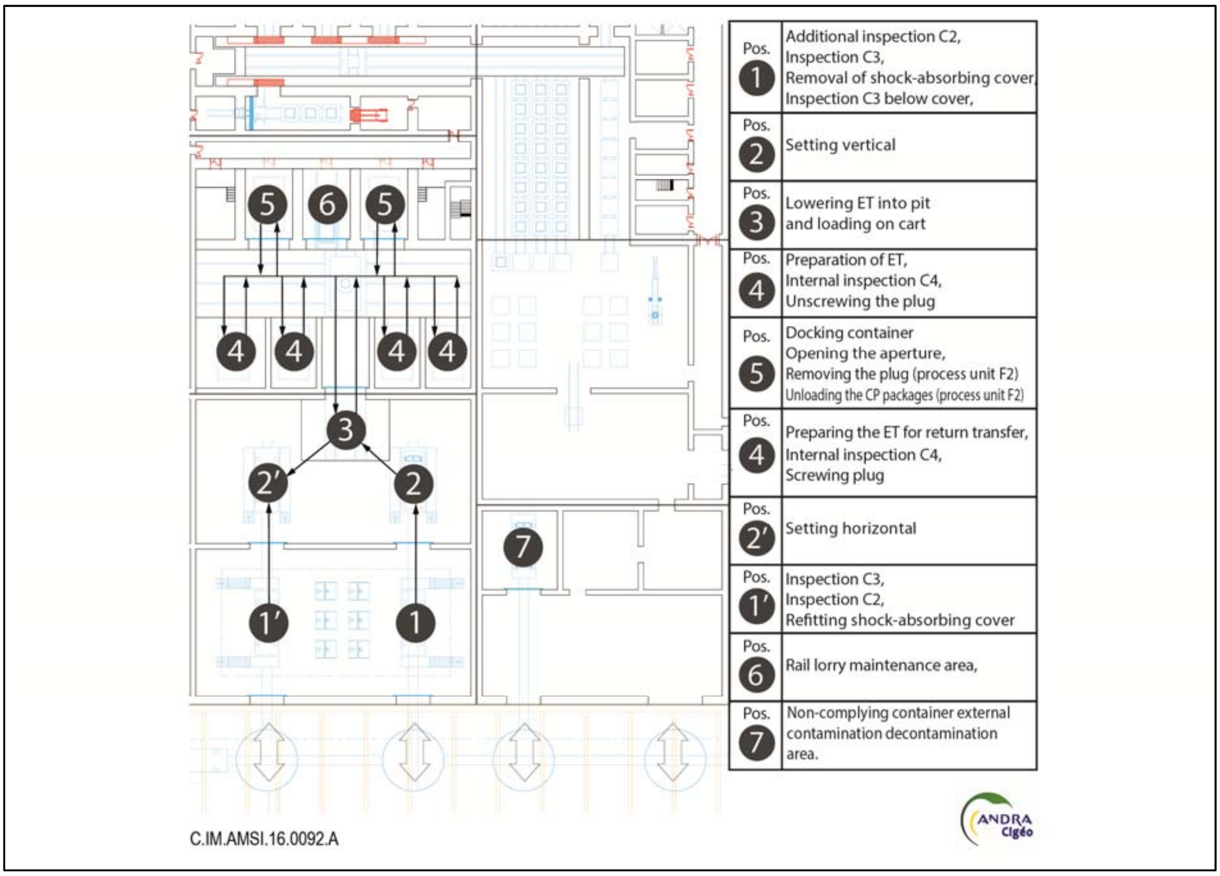

Figure 3.3-3 Preparation and unloading of ET-HV at level +0.00m and -4.50 m (illustration at the end of basic engineering design)

Vertical containers are placed in the unloading bay in order to perform the following main operations shown in Figure 3.3-4:

The first operation performed in the unloading building consists in removing the protective cover from the container by means of the existing bridge crane. The container is tipped vertically upright in order to be set down on a transfer cart located in a pit, by means of an adaptor frame (see figure below).

A storage area is provided for storing the protective covers and the handling beams.

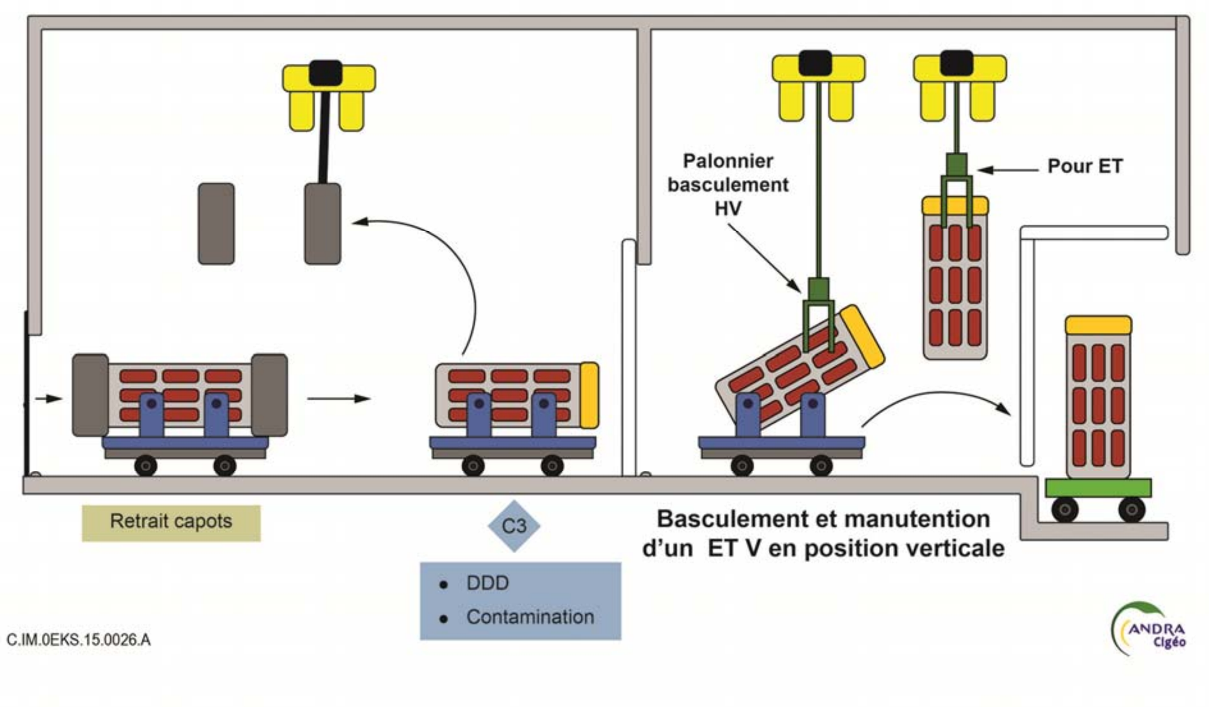

Figure 3.3-4 Schematic diagram of the reception and tipping of transport containers into the vertical, position

Once placed on the transfer cart, the container[42] is taken into one of the four preparation rooms where the mechanical covers are removed from the container and the docking flanged is installed.

The docking principle adopted is to install an individual adaptor on each container to interface with a common docking device The transport containers are positioned by the facility's handling systems.

Once the container is docked, the cover is removed. The packages are then unloaded by means of a cell bridge crane and set down on a buffer storage rack to await availability of downstream operations if required.

The operations performed in the preparation cell before and after unloading and in the vertical transport container unloading cell are performed at level +6m of the facility (see Figure 3.3-4).

- **Horizontal transport containers**

The horizontal transport containers are placed in the unloading building in order to perform the following operations (Figure 3.3-5):

[42] Contamination checks are planned on vertical or horizontal transport containers. In the event of non-compliance, the containers will be transferred to the processing room situated close to the convoy loading/unloading bay for decontamination. After decontamination, the container is routed into the full container buffer zone for reinsertion into the conventional unloading chain.

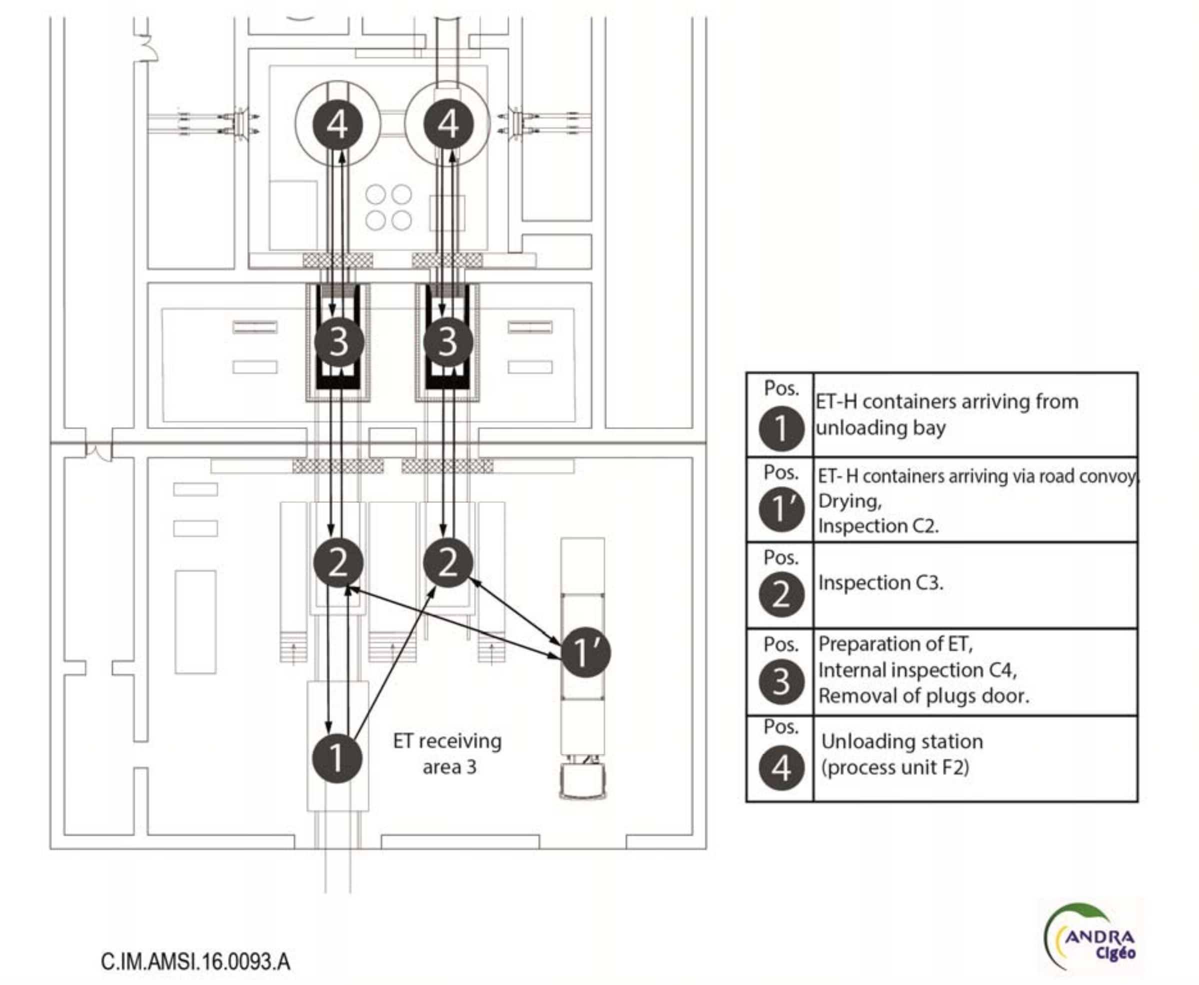

Figure 3.3-5 Preparation and unloading of ET-H at level +0.00m (illustration at the end of basic engineering design)

The container firstly undergoes inspection (station 1). If it conforms, the container is readied for unloading. This involves first removing its protective cover[43] (station 2). The end of the container is then placed by means of the transfer cart inside a cell in order to remove the door (station 3). This cell is designed to protect the operating personnel against radiation.

Setting-down areas are provided in the receiving area for storing the various components removed from the containers as well as the various handling beams.

The RD39 container is unloaded via a retractable transfer table docked to the door of the automatic package pusher of the transport container.

A transfer cart deposits the primary packages on Cigeo pallets in a buffer zone.

3.3.3 Process unit F2: Placing packages in disposal containers

3.3.3.1 Unloading, inspection and loading of primary packages

a) Vertical transport containers

The primary packages are extracted from the vertical transport containers at level +6m.

[43] In the case of a ISO 20' type container, this only involves opening the door.

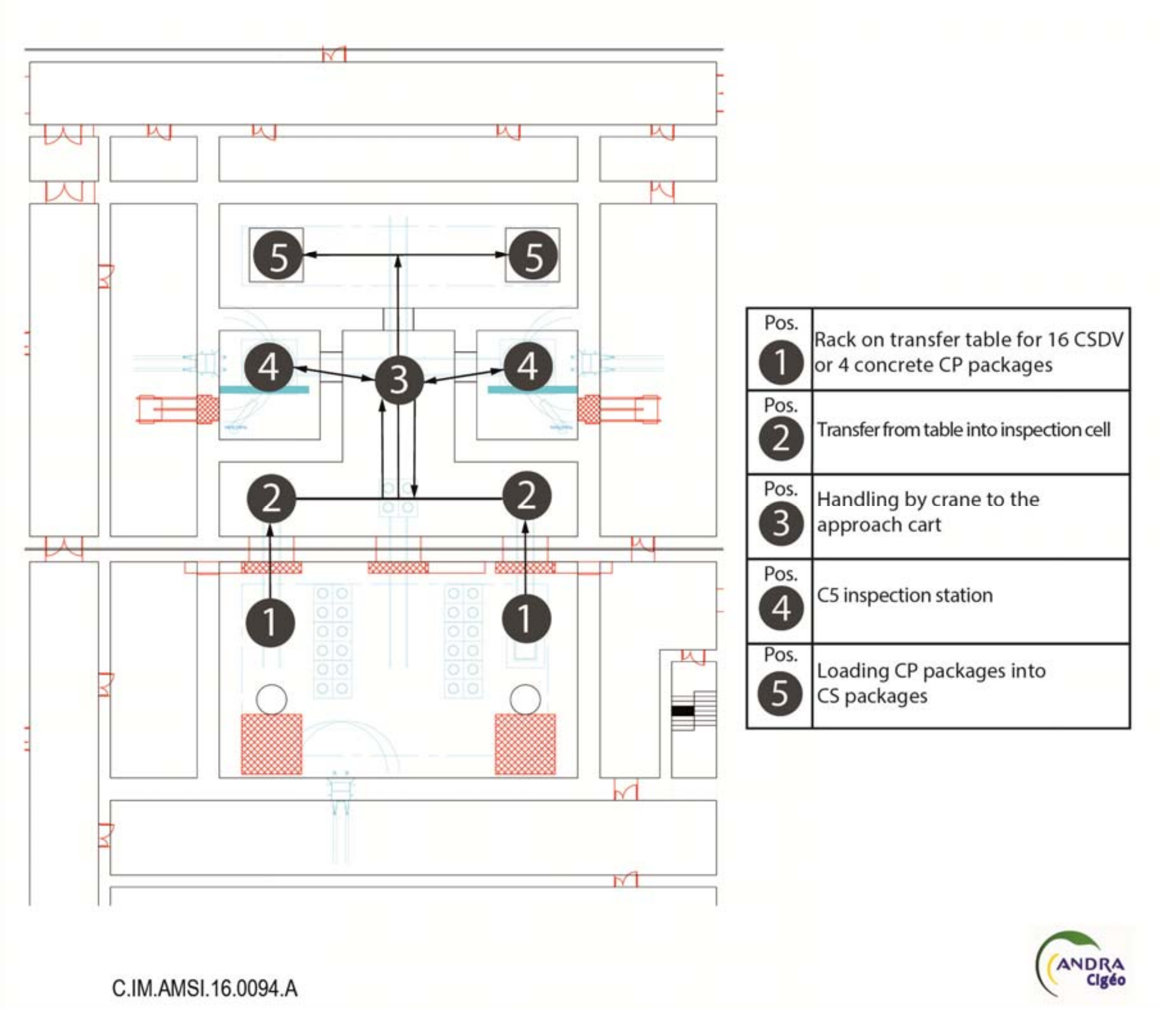

Figure 3.3-6 *Unloading, inspection and loading cell for loading primary packages from ET-V containers into disposal containers (illustration at the end of basic engineering design)*

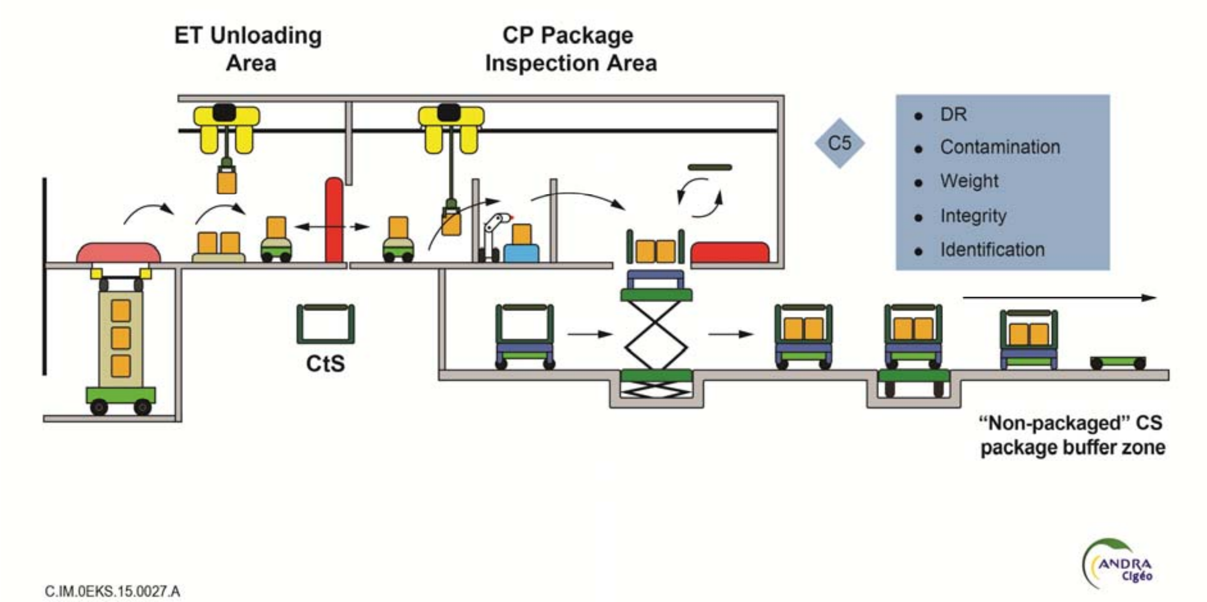

Figure 3.3-7 Schematic diagram of ET-V container unloading (end of the basic engineering design)

The reception cells for packages from vertical transport containers (ET-V) enable packages to be received on the floor at +6,00m, where the following operations are performed:

- docking of containers;
- opening and closing of containers;
- unloading of primary packages from containers;
- storage of primary packages on transfer table;
- transfer of primary packages to the first level inspection cell ;
- inspection of primary packages;
- decontamination at the package at the package inspection station (dry or under water);
- loading of primary packages in disposal container via openings;
- placing and removal of the covers of ILW-LL disposal containers by means of a jib.

The primary packages are unloaded from the transport container by means of special grippers complying with the volume gripping requirements of the containers. The packages are thus unloaded from the container onto a transfer table (station 1), the number of packages unloaded being adapted to their volume (capacity to receive between 4 and 16 packages at this stage). The transfer table for transferring the packages towards the inspection and loading cells is designed to limit the handling height. Guard rail and end stop systems are installed to prevent the packages from tipping.

The ("C5") inspection cells for primary packages from vertical transport containers enable the following inspections to be performed at reception:

- **visual** inspections of the outer appearance of the waste packages. The visual inspections also include checking the package ID number
- **dimensional** inspections, which also include weighing to check the actual weight of the waste package and to determine the void fraction after additional checks,
- **non-contamination** inspections by means of smear samples,
- **dose rate measurement** checks for mapping the dose rate measurements at contact and at 1 metre.

According to the contamination level detected, it will be treated by a robot (dry treatment process) or by high-pressure water spraying in the decontamination cell (station 6).

If the primary package is deemed to conform, it will be loaded into its disposal container by means of a gripper adapted to the package geometry.

The disposal container is transported to the conditioning cell by means of a cart / transfer carriage system. A lift platform system takes the disposal container into the loading cell located at +6m.

Once the packages are placed inside their disposal container, the pallet is made available at the +6m level to be transferred to Process unit F3 “Conditioning/deconditioning of disposal packages”.

During the disposal container package loading phase, the disposal container is positioned at mid-height relative to the ground in order to limit the drop height.

b) <u>Horizontal transport containers</u>

The primary packages and disposal containers are extracted from the horizontal transport containers at level +0m.

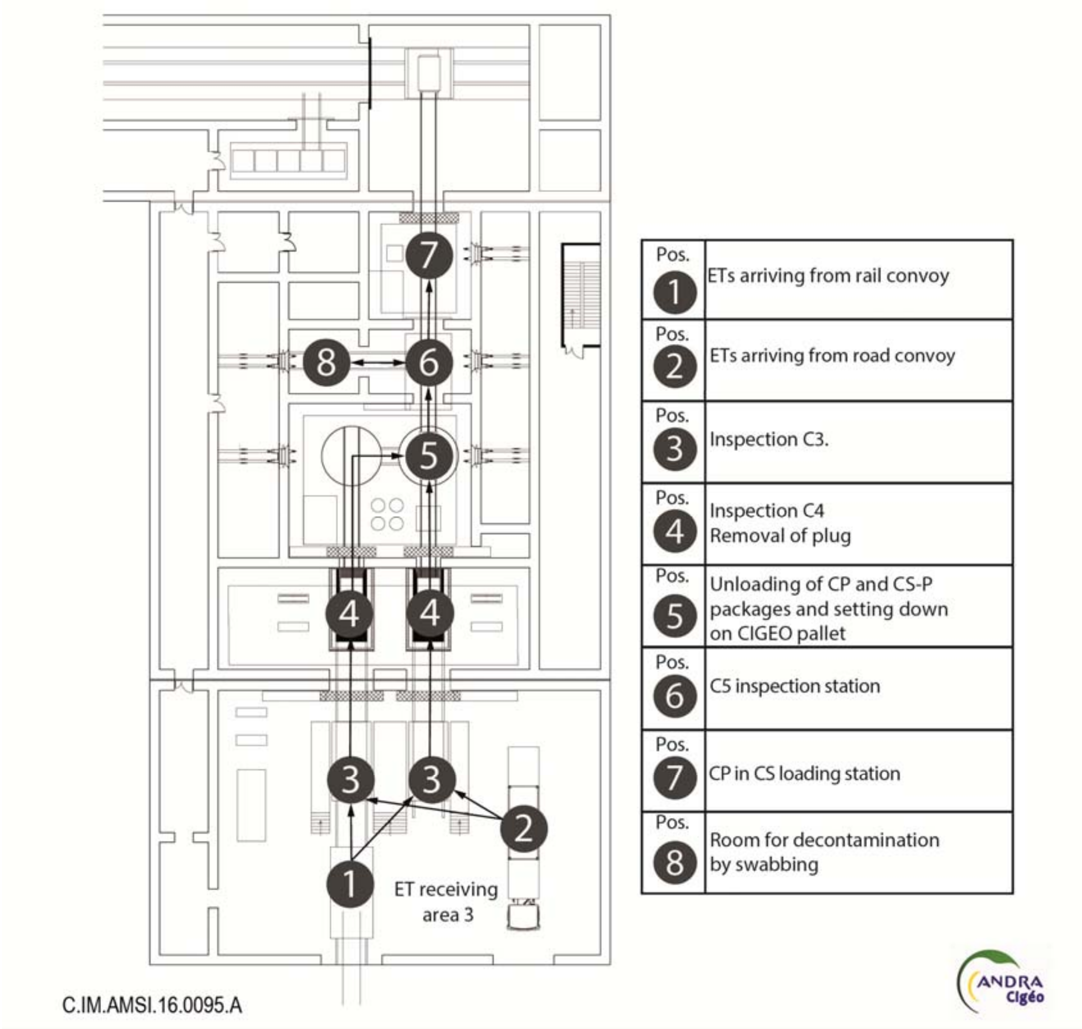

Figure 3.3-8 *Unloading, inspection and loading cell for loading primary packages into disposal containers (illustration at the end of basic engineering design)*

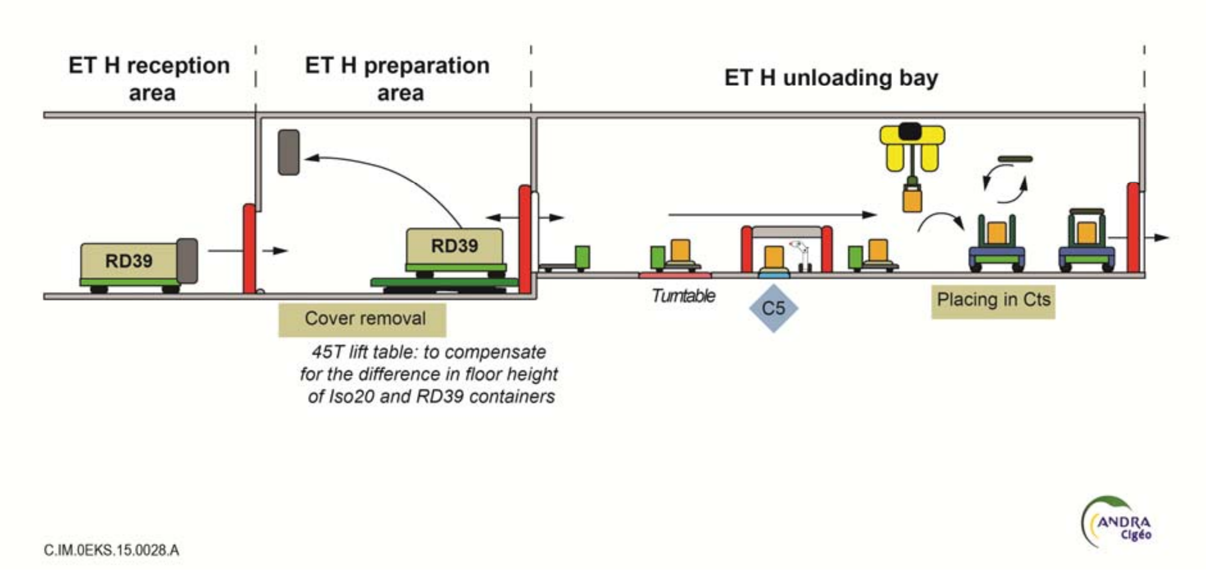

Figure 3.3-9 Schematic diagram of ET-H unloading

The reception cells for the packages coming from horizontal transport containers (ET-H) serve to transfer the primary packages from the unloading areas to the “C5” inspection cell that is common to the vertical transport containers (ET-V).

It should be noted that the ET-H building, unlike the ET-V building, does not have a high pressure water decontamination cell. The decontamination cell is equipped with a robot for fixing the contamination or treating contamination with swabs.

c) Disposal container supply

The disposal containers are supplied by truck or train. An airlock is provided at the surface for unloading and checking the conformity of the containers. Disposal containers that are deemed to comply are transferred to the buffer zone. The containers deemed not to comply are returned to the manufacturers’ sites.

The disposal container is then carried by a transfer cart, located on top of a transfer carriage serving one of the loading openings, or passes through the pallet inspection cell to serve the ET-H building.

The sequence of operations for the disposal containers is as follows:

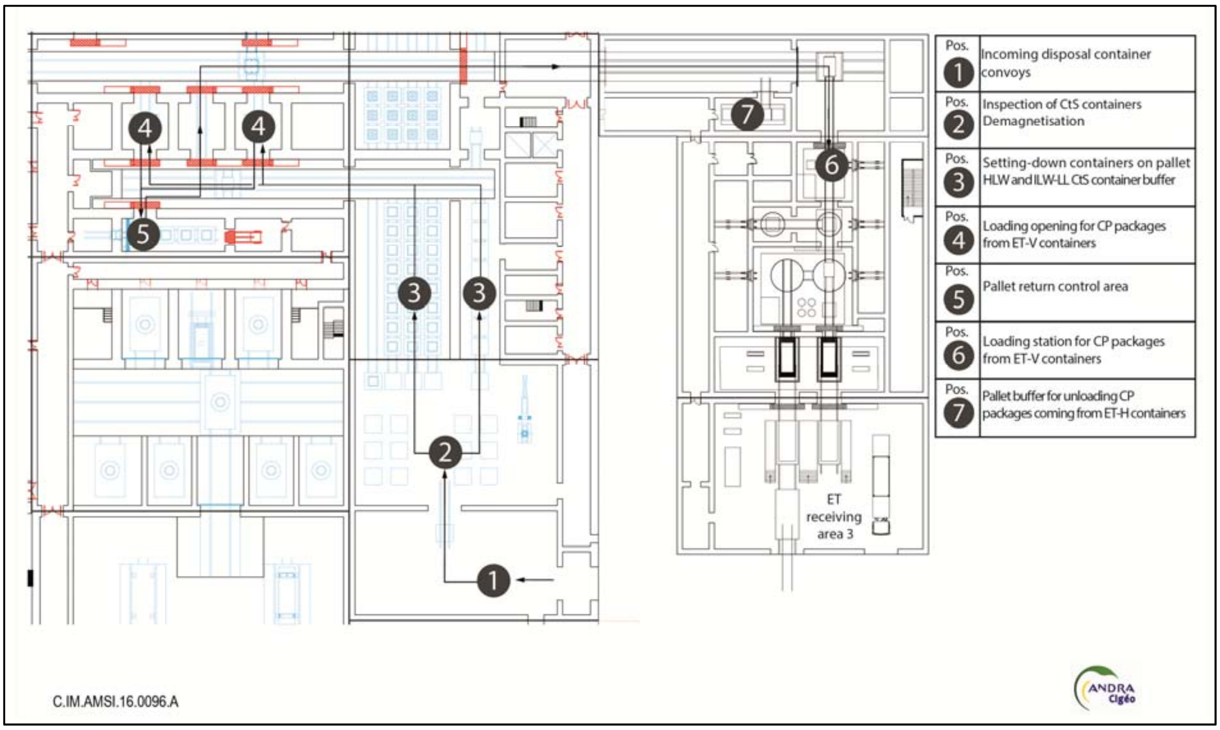

Figure 3.3-10 *Disposal container supply process (illustration at the end of basic engineering design)*

3.3.4 Process unit F3: Conditioning/deconditioning of disposal packages

3.3.4.1 Conditioning of ILW-LL disposal packages(excluding ILW-LL primary packages placed directly in the disposal cell)

Once the ILW-LL primary packages are placed in the disposal containers (in red in the diagram below), they are:

- Either placed in a conforming package buffer zone (in blue in the diagram below) ,
- Or placed in a non-complying package buffer zone to await a decision (in yellow in the diagram below),
- Or sent to the conditioning cell (in green in the diagram below).

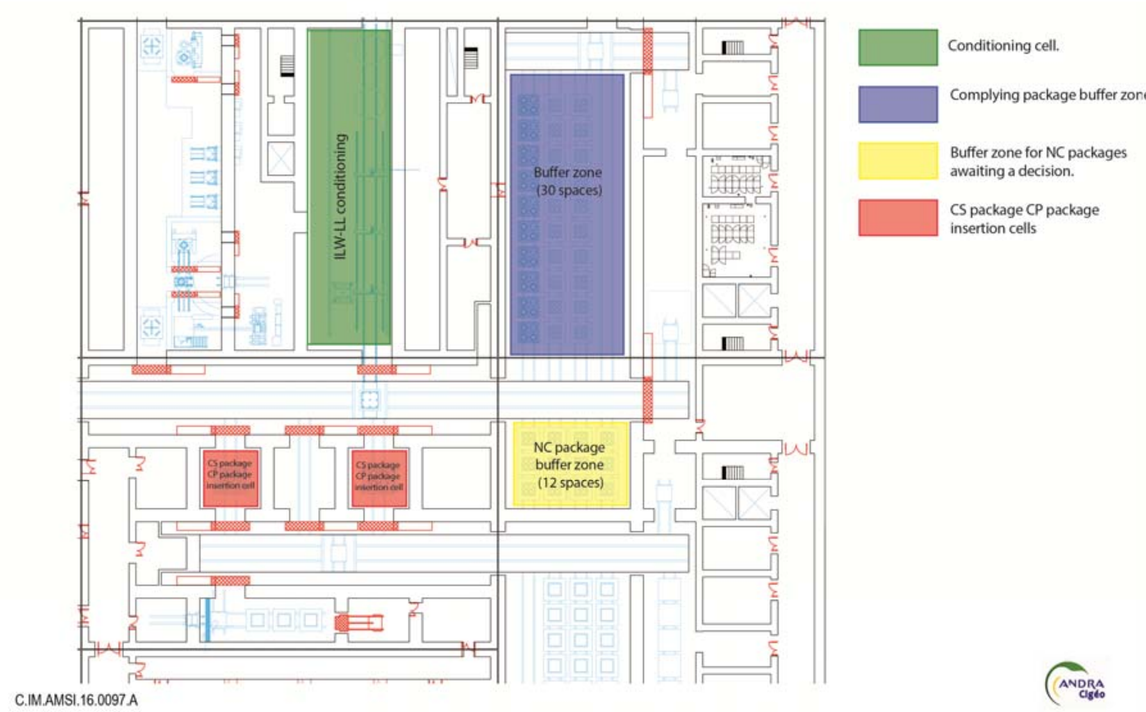

Figure 3.3-11 Location of ILW-LL conditioning (illustration at the end of basic engineering design)

The pallet + primary package are inserted in the disposal container by means of a transfer cart and platform assembly.

- The disposal packages are transferred between stations in the ILW-LL conditioning cell using a type of cart performing the same pallet + primary package transfer and lifting functions,
- Lid grouting operations can be carried out on ILW-LL disposal containers in the conditioning cell if required (see packages section). Performing these operations in the cell is liable to generate potentially contaminated deposits (dust from grouting). The principle adopted is to run the carts along separate tracks to avoid spreading these deposits throughout the facility.

The conditioning sequence adopted for the operation is as follows:

- reception of a pallet of waste packages inside a disposal container via transfer cart:
- removal of lid;
- injection of graded binder;
- refitting of lid;
- transfer of disposal package to station 2;
- placing clamping screws;

- mechanical tightening of lid;
- transfer of disposal package to station 3;
- grouting of lid if required;
- transfer of disposal package to station 4 or 5 ;
- C6 inspection of storage package;
- removal of storage package.

The ILW-LL disposal packages undergo the following inspections:

- **Visual inspection of disposal packages** to detect any package defects. The visual inspections also include checking the package ID number
- **Dimensional inspections of disposal packages**. The dimensional inspections include weighing to check the actual weight of the disposal package and indirectly check the void fraction.

All internal transfers within the conditioning are performed using a dedicated cart.

3.3.4.2 Conditioning of HLW disposal packages

Once the HLW primary packages are placed in the HLW disposal containers (in red in the following diagram), they are:

- either placed within a buffer zone for primary packages in disposal containers (in blue in
- the following diagram),
- or placed in a buffer zone for non-complying packages in disposal packages to await a decision (in yellow in the diagram below),
- or sent to the conditioning cell (in green in the diagram below).

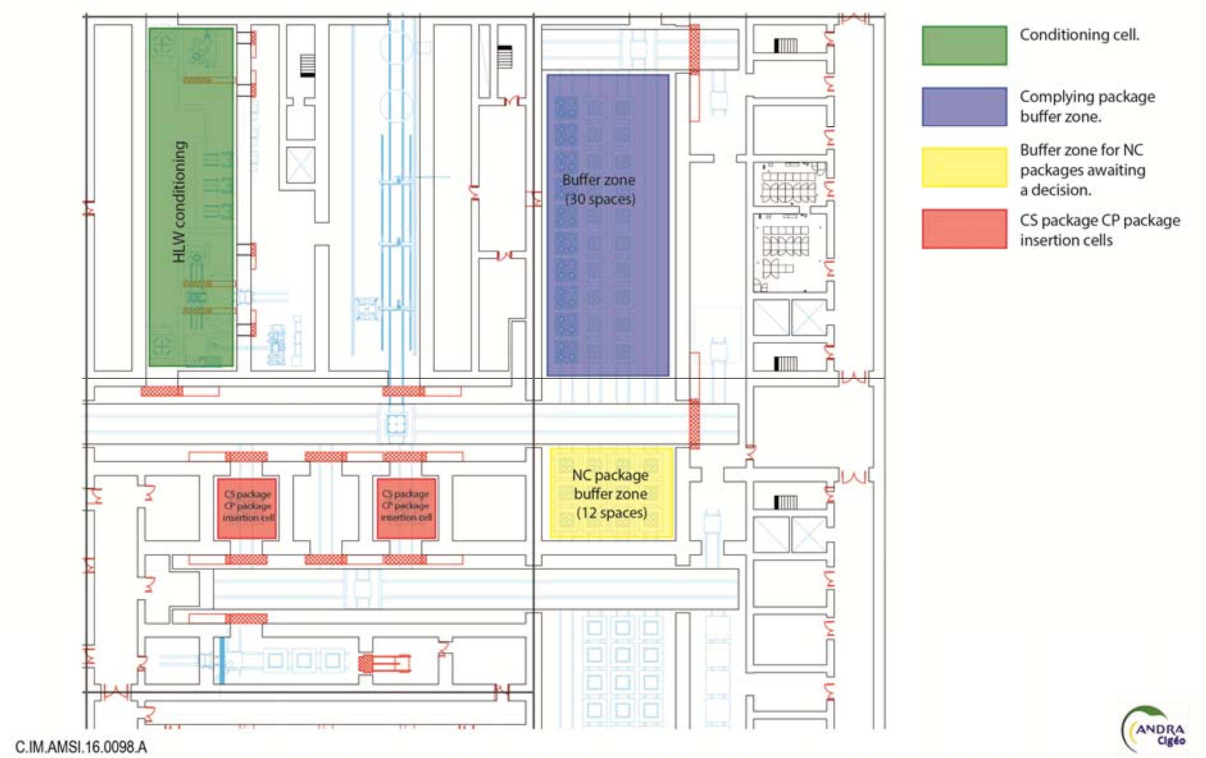

Figure 3.3-12 Location of HLW conditioning (illustration at end of basic engineering design)

The unclosed HLW disposal containers and the lids arrive at the entrance to the conditioning cell on transport pallets. The pallets are handled by means of carts.

The following operations can be performed in this cell: lid placement on container body, electron beam welding of the lid, thermal stress-relieving, weld bead machining and weld ultrasound inspection.

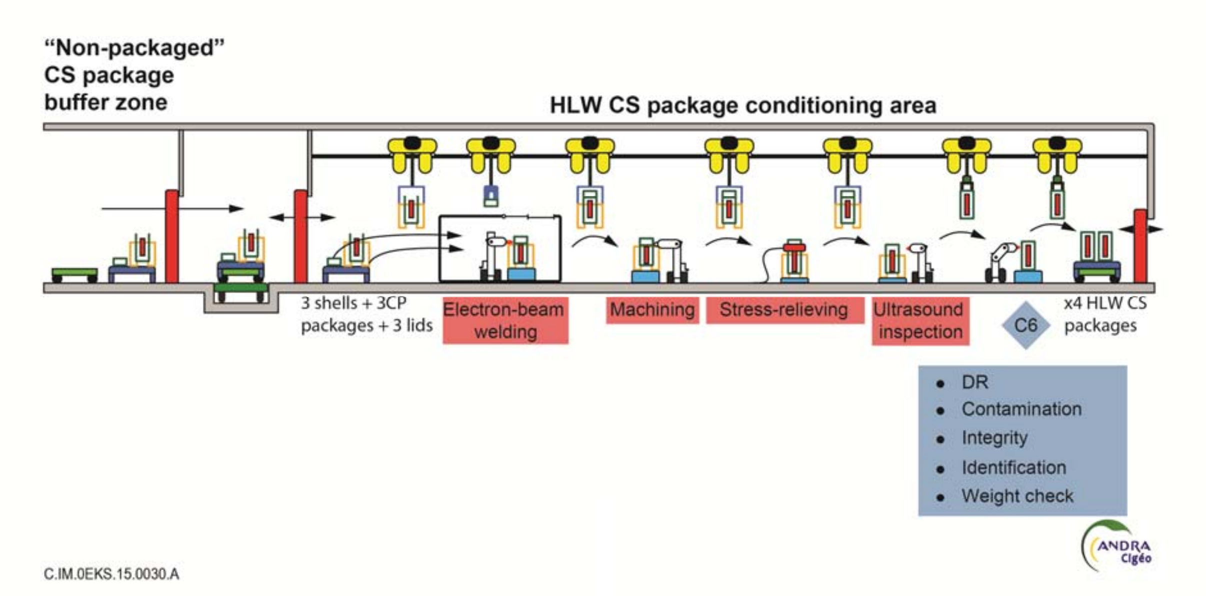

Figure 3.3-13 *Schematic diagram of HLW conditioning (illustration at end of the basic engineering design)*

The adopted operating sequence is as follows:

- reception of a pallet of primary waste packages inside a disposal container via transfer cart:
- placing of lid at the lid placing station;
- transfer of HLW disposal container with unwelded lid to the welding station;
- welding of lid onto the container;
- transfer of welded disposal package to stress-relieving station;
- stress-relieving of HLW disposal package;
- transfer of HLW disposal package to the machining / planing station;
- machining/planing of weld bead;
- brushing of welded area;
- transfer of HLW disposal package to the inspection station.

The following inspections are performed at the inspection station:

- **ultrasound weld inspection** to check that a defect-free "full wall thickness" weld is achieved between the lid and the body of the disposal container;
- **visual inspections of disposal containers** which include checking the package ID number;
- **dimensional inspections of disposal packages** which also include weighing to check the actual weight of the disposal package.

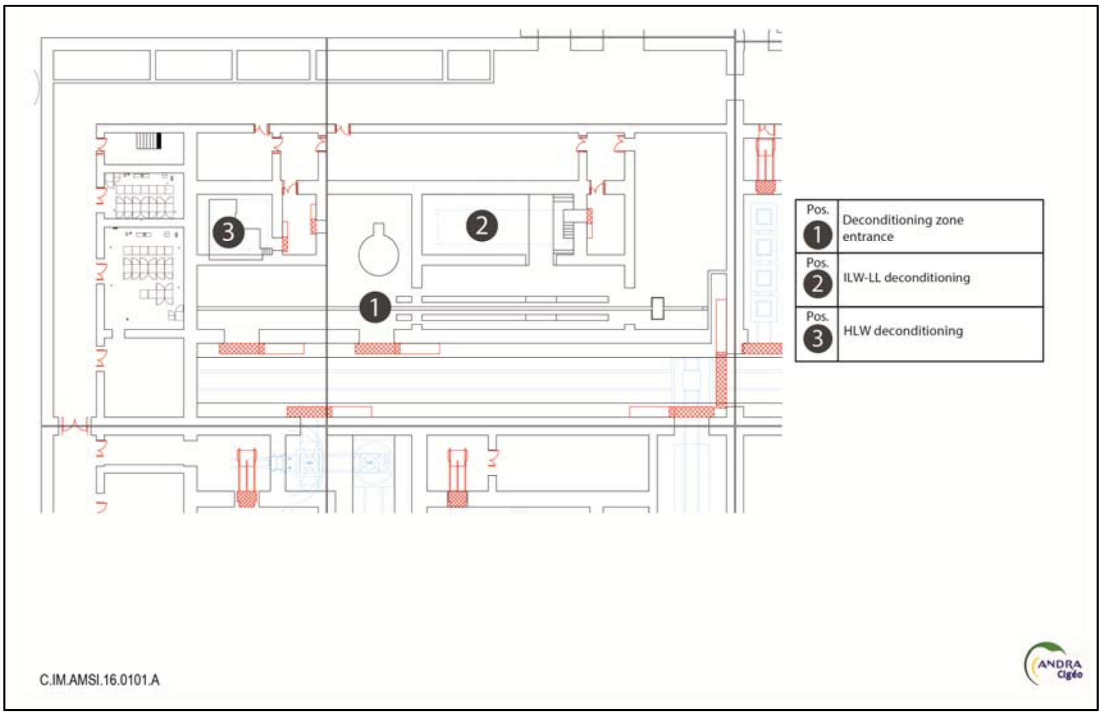

Figure 3.3-15 Deconditioning cell (illustration at the end of basic engineering design)

3.3.4.3 Cell for loading primary packages in disposal containers

This cell (in blue on the appended figure) serves to recondition primary packages outside the nominal flow, in particular coming from the deconditioning cells

The following inspections are performed in this cell:

- Visual inspections to detect defects such as cracking, chipping, perforations or areas of corrosion,
- Dimensional inspections. The dimensional inspections include weighing to check the actual weight of the waste package and check the void fraction,
- Non-contamination inspections by smear tests that are checked in an in-zone glove box,
- Dose rate measurement checks for mapping the contact dose rate measurements and the measurements at 1 metre.

3.3.5 Process unit F4: Placement of disposal packages in casks

Once the HLW and ILW-LL disposal packages have been inspected, they are placed in a buffer zone (in blue in the diagram below), to await transfer to the underground facility.

Note: Grouted ILW-LL packages are stored until the grouting binder has cured.

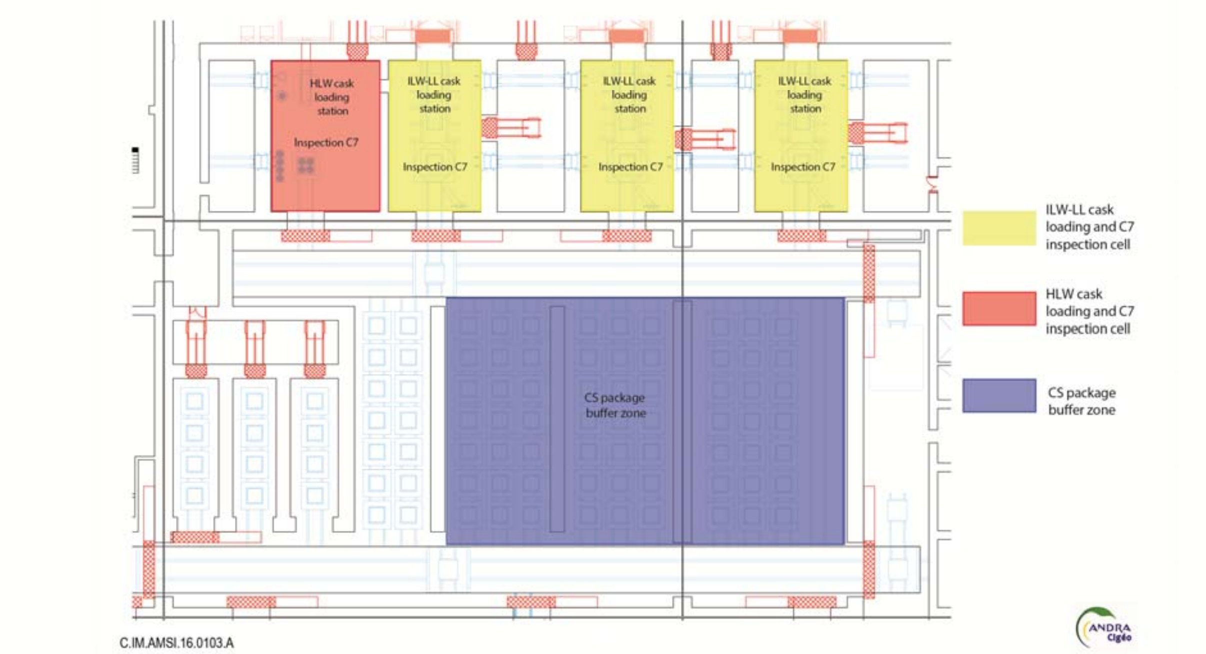

Figure 3.3-17 *HLW and ILW-LL disposal container buffer zone and cask loading cells (illustrations at the end of basic engineering design)*

The disposal package is transferred via a secondary cart/ transfer carriage in the cell within which a "C7" inspection is performed. After inspection, the disposal package is placed on a loading table provided for the cask loading system previously docked to the wall of said cell. HLW packages require to be placed in a horizontal position for loading into the cask. This is done by means of a tipping device (in red in the diagram below).

The disposal packages are supplied by a transfer cart/platform system used in the rest of the facility.

Note: A ILW-LL disposal package reconditioning zone is provided in the C7 inspection cell (in green in the diagram below) to receive packages deemed not to comply[44]. These are then decontaminated then placed in a cask (in yellow in the diagram in appendix 16).

3.3.5.1 Loading of HLW disposal packages in the casks

The HLW disposal packages arrive in the cask loading cell vertically on a pallet:

- a buffer zone is provided upstream of the inspection area for these packages;
- the packages are transferred to the upending station one at a time;
- bridge crane covers the whole of the cell.

The reference HLW disposal package tipping device comprises:

- a frame anchored to the floor and the wall of the cell;
- a cradle for receiving and upending the HLW disposal package;
- a moving basket for sliding the HLW disposal package onto the cradle, for adapting the size of the basket to the different disposal package diameters (Ø580MAX or Ø645MAX)[45] and for docking the package at the partition opening

[44] This cell can also be used in the event of retrievability operations
[45] Diameters 580MAX or 645MAX

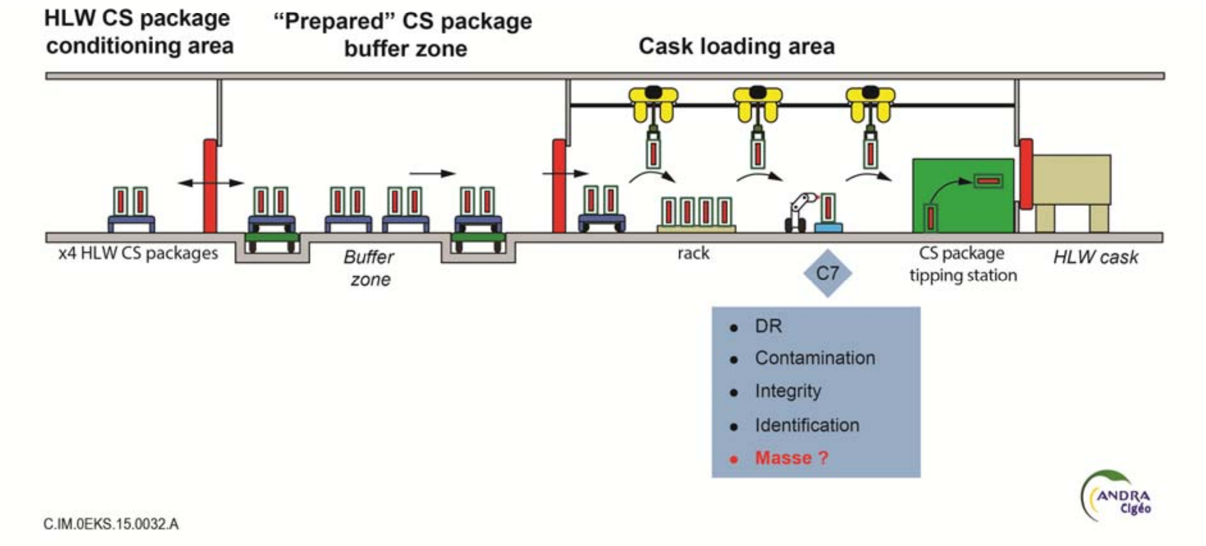

Figure 3.3-18 Schematic diagram of HLW disposal package loading in casks ((illustrations at the end of basic engineering design)

The frame supports the pivoting connection with the cradle. This is positioned in such a way that, when horizontal, the HLW disposal package is at the elevation (centreline) of the opening for transfer to the cask.

Tipping is ensured by a trapezoidal screw jack coupled with an onboard electric motor. The movement is thus made irreversible. This actuator is designed to enable tipping from vertical-to-horizontal and horizontal-to-vertical when the package is positioned at the end of the cradle. The travel is controlled by limit switches together with redundant mechanical end stops. The possibility of offsetting this drive will be confirmed at the detailed design stage. In the event of a fault on the tipping drive, provision is made for a manual control accessible via the cell's remotely-controlled manipulator arms.

The cradle consists of a robust mechanically-welded structure supporting a stainless steel carrier, providing two contact surfaces for interfacing with the sliding runners of the HLW disposal packages (see packages section) and ensuring contact between the package and the cradle along two lines of its surface (for the range of HLW package diameters) and in particular enabling the HLW disposal packages to slide on its runners. The cradle carries the items for sliding the basket and thus the package. The basket is driven by a trapezoidal screw jack coupled with an electric motor drive ensuring the irreversibility of the movement. The basket is guided along the cradle by guide rails and runners designed to support the forces generated during translation and tipping.

The basket is provided with a mechanical system without electrical actuator to adjust to the diameter of the package to be tipped and thus avoid unwanted movement of the package during tipping. Two hoops fitted with a sliding cam and roller mechanism slide under the effect of the translation motion imparted as the package is raised into position.

The cradle helps correctly position the disposal package ready for transfer into the cask. The process also works in the opposite direction, in the event of a transfer from the cask to the tipping station. The angular orientation of the package is adjusted on the inspection station before the tripping station (inspection C7).

3.3.5.2 Loading of ILW-LL disposal packages in the cask

Once inspected, the disposal package is transferred by cart into one of the three ILW-LL cask loading cells.

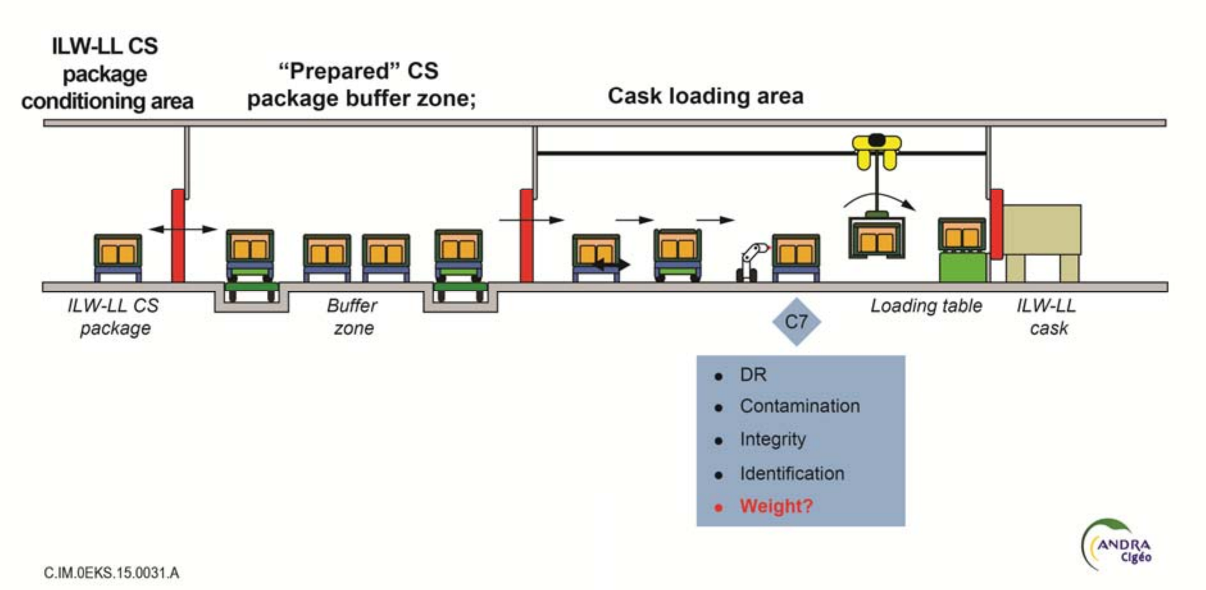

Figure 3.3-19 Schematic diagram of ILW disposal package loading into casks ((illustrations at the end of basic engineering design)

The ILW-LL disposal package is set down on the cask loading table. The equipment for performing the transfer from the pallet to the loading table will be specified as part of the detailed design phase.

3.3.6 Process unit F5: Sampling test inspections

The sampling tests of the packages take place outside the package conditioning operations within the operating flow. The cells associated with these inspections are located within the sampling inspection, non-conformity and waste management building.

The types of measurement will be specified following the discussions currently being undertaken with the waste producers aimed at guaranteeing package quality, taking into account the measures which will be implemented within their own facilities prior to shipment of primary packages to Cigeo.

The zone receiving these measures will be adaptable according to the needs associated with the different types of waste package and the delivery schedules.

At the end of the inspection process, the packages return to the operating flow or are directed towards the nonconforming package management cells, located within the same building, for suitable treatment.

3.3.7 Process unit F6: Management of nuclear and conventional waste

This interdisciplinary process unit includes all the rooms and equipment associated with the management of nuclear and conventional waste linked with the management of operating waste.

The rules and good practices of waste management meeting the requirements are given below:

- separate the different flows as much as technically possible (mixing forbidden);
- collect liquid effluent at source, use recovery tanks enabling inspections;
- ensure the contents of the tanks can be homogenised and samples taken;
- reduce the volumes of waste;
- process waste in situ or be in a position to transfer it to external outlets;
- ensure it can be sent to an external processing and conditioning centre;
- ensure that mobile processing and conditioning units can be accommodated.

a) Management of solid conventional waste

Conventional waste is stored at dedicated collection points. Waste removal is managed in such a way as to avoid excessive accumulation of waste.

The storage areas are designed to receive all types of waste (inert waste, non-hazardous waste and hazardous waste) of all sizes.

The location of the collection skips during the construction and dismantling phases depends on the associated site restrictions. They can be moved to optimise the evacuation flows.

During operation and the maintenance and renovation operations, the waste produced is transferred to collection points. Their location takes account of the waste generating areas within the facility and the accessibility from outside the facilities.

b) Solid nuclear waste management

Solid nuclear waste is potentially generated during the following operations:

- non-contamination controls at check points;
- decontamination of packages;
- processing of non-complying packages;
- “hot” laboratory analyses;
- maintenance and renovation of equipment in nuclear waste zones (ZDN);
- dismantling of rooms in the nuclear waste zone ;
- changing of ventilation filters;
- discharging in effluent room.

Nuclear waste products[46] are sorted as close as possible to the source of generation. Sorting is carried out by considering the physical nature of the waste, the radiological category and the spectrum (linked to the waste generation area).

The waste products are grouped in suitable containers for each type of waste identified. Operating waste is therefore directly conditioned in a packaging (vinyl bag or metal drum) in the production area then taken to the operating waste treatment room to be processed on site (if applicable) or conditioned in a suitable packaging for transport to an external treatment centre (if applicable) or to a conditioned waste disposal centre (Cires or CSA centres). According to the nature of the waste and the packaging used, internal transfers will be performed by means of the existing operating equipment or special waste management equipment.

[46] During dismantling operations, bulky items of waste will be collected directly in the appropriate containers (depending on the radiological category), according to their physical nature (metal waste or rubble) if space permits.

The thickness of the vinyl envelope may vary according to the radiological hazard considered (alpha or beta-gamma). A single-layer vinyl envelope is sufficient for waste containing beta-gamma radiation-emitting radioelements, while a double- or even triple-layer envelope is necessary for waste containing alpha radiation-emitting radioelements.

Following in situ collection at the place of generation, the waste products must be sent to the waste treatment area where they will be prepared for final disposal before removal.

Operating waste (technological waste, small tooling, defective equipment from nuclear waste zones (ZDN)) are transferred to the operating waste treatment room. The treatment operations envisaged are decontamination, volume reduction and conditioning. The room will comprise in particular:

- decontamination devices: wet swabs, ultrasound tank, vacuumable dry gels, high pressure jet, etc.;
- volume reduction devices: cutting table, circular saw, sabre saw, shears, plasma station, nibbler, press, etc.;
- conditioning equipment: VLLW or LILW boxes, drums, vinyl welder, etc.;
- handling equipment: gantry crane or monorail crane + hoist (capacity and coverage to be defined), lift truck, drum carrier, etc.

3.3.8 Process unit F7: Process support

The support functions covering all the identified processes are:

- the support infrastructures
  - ✓ physical supports (e.g.: civil engineering, ventilation, etc.);
  - ✓ technical support (rooms, ancillary areas);
- the support processes (cell, workshop, analysis laboratory equipment, etc.)

Access is gained to the HLW conditioning cells, in the absence of source term, in several ways:

- plugs doors located in the rear central area;
- Bridge crane parking door;
- over-cell opening.

The bridge crane parking area also has an upper opening for crane girder disassembly and the insertion of equipment into the bridge crane parking area.

Each cell also has a forward zone with local control stations reserved for degraded operation situations.

Finally, in maintenance situations, it is planned to enable storage of all the packages in the buffer zones and exceptionally to give access to the process circulation corridors to members of personnel.

3.3.9 Handling equipment families up to cask loading

The handling equipment for the surface process is grouped into three families:

- lifting and handling equipment;
- ground handling equipment;
- handling and lifting accessories.

3.3.9.1 Lifting and handling equipment family

This family comprises the following items of equipment:

- Gantry cranes: Gantry cranes are commonly used in industrial lifting and handling applications, in particular in port facilities. Standard technical solutions are therefore adopted in the surface nuclear building process,
- Bridge cranes: The specific characteristics of certain lifting and handling operations performed in the Cigeo surface nuclear facility are linked to the nature of the packages handled. The bridge cranes operate within the "hot" cells where direct human intervention is not possible due to the irradiating or contaminating environment As a result, the bridge cranes of the Cigeo surface nuclear facility are grouped into three categories:
  - ✓ "Standard" bridge cranes: these require no adaptation to a nuclear environment and meet the safe lifting and transfer requirements associated with the applicable conventional regulations;
  - ✓ "Special" bridge cranes: these cranes have special requirements to take account the specific characteristics of the packages handled. They are designed to limit the risk of dropping, knocking or hitting the package through special mechanical design margins and the installation of failure detection devices.
  - ✓ "Nuclear" bridge cranes: these cranes operate within "hot" cells and require to meet specific nuclear requirements associated with an irradiating and partially contaminating environment.
- Lift platforms: Lift platforms are commonly used in industrial and nuclear lifting and handling applications. Standard technical solutions are therefore adopted in the Cigeo surface nuclear process,

3.3.9.2 Ground handling equipment family

This family contains the following equipment:

- Transfer carts: The transfer carts are items of handling equipment which serve mainly to transfer a load within a cell or between two process zones without a change of direction. The load is in most cases set down using the bridge crane and the carts cover short distances (less than 25 metres);
- Transfer with lifting carts: Transfer with lifting carts are items of handling equipment which incorporate a lifting function for transferring a load from one process zone to another;
- Transfer carriages: Transfer carriages are items of equipment that run in pits to transfer other items of equipment (carts) horizontally within the facility;
- Frames: These items of equipment serve to transfer transport containers from the outside to the inside of the facility. The movement of these items of handling are guided by rail. The position of the equipment along the rail is determined by position sensors installed along the route.

3.3.9.3 Handling and lifting accessories family.

This family comprises attachments such as lifting beams, grippers, support frames, transfer pallets and handling baskets

3.3.10 **Management and transfer of casks up to the ramp transfer system**

3.3.10.1 Intermediate-level long-lived waste (ILW-LL) casks

The ILW-LL casks differ from one another in size according to the ILW+LL packages to be transported and the thickness of their shielding. Adjustment systems within the inner cavity enable the cask to be adapted to accept various package geometries and in particular to limit the movement of the package within its cask in the event of impact. The maximum design weight for the horizontal equipment is 90 tonnes.

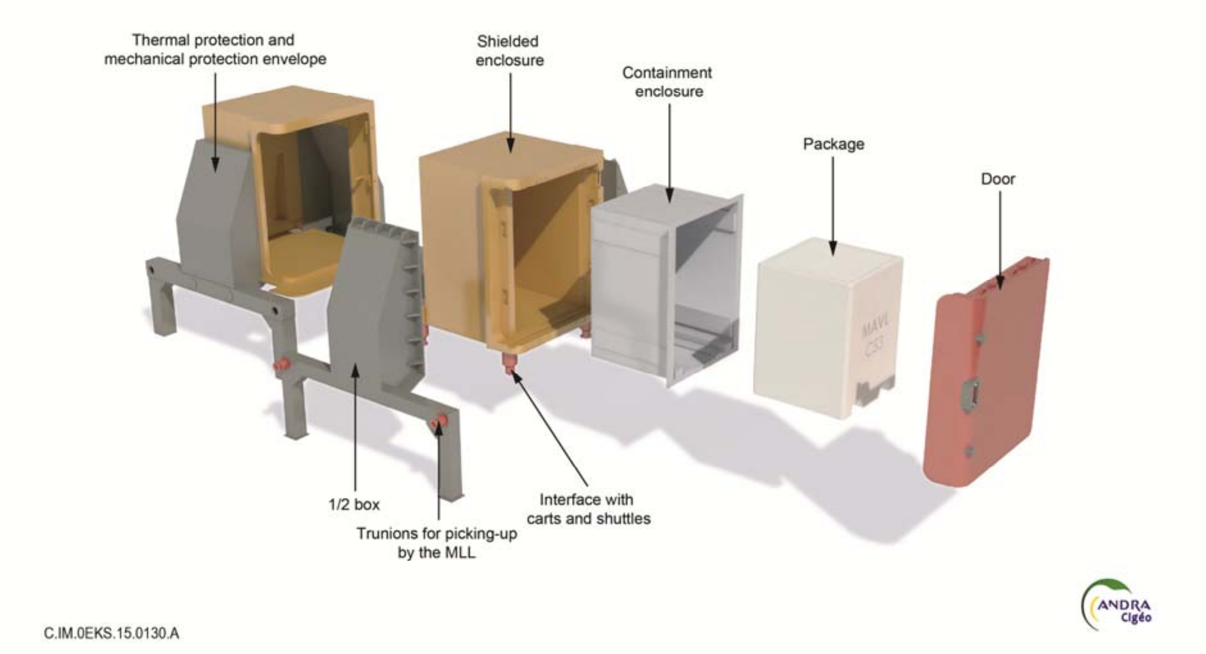

Figure 3.3-20 Exploded view of the components of a ILW-LL cask

There are three types of cask suitable for containing the different types of ILW-LL disposal package:

- type 1:casks for transporting type CS2 and CS3 ILW-LL disposal packages;
- type 2:casks for transporting package types CS1, CS4, CS6 and CS7;
- type 3:casks for transporting package type CS5.

The three types of cask are shown in the figures below.

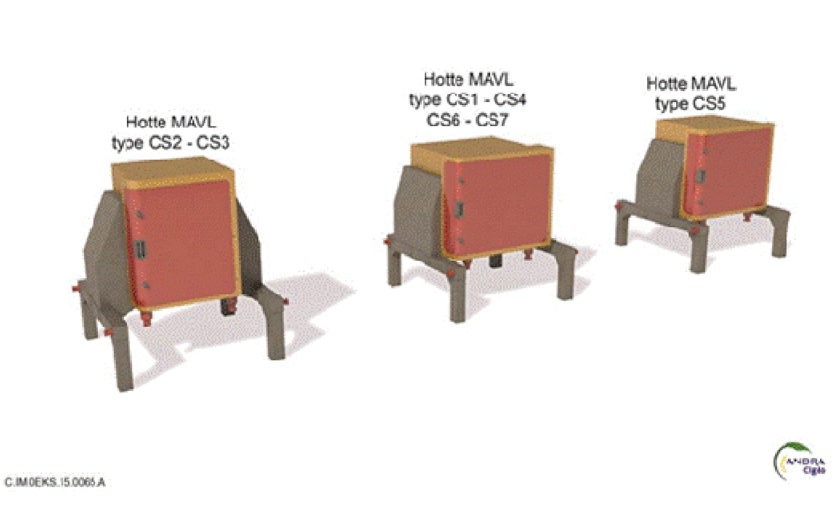

Figure 3.3-21 Different ILW-LL casks

The characteristics of the three types of cask at the basic engineering design stage are presented in the table below.

Table 3.3-1 Main characteristics of ILW-LL casks at this stage

Cask type	Associated packages	Max. weight of package (in t)	Weight of cask and package (in t)	Height of cask (in mm)
Type 1	CS 2	13	85	4490
	CS 3	13	85	
Type 2	CS 1	11	74	4210
	CS 4	15	78	
	CS 6	17	80	
	CS 7	16	79	
Type 3	CS 5	16	87	4240

3.3.10.2 High-level waste (HLW) casks

These casks are motorised for performing docking / insertion into the cell / retrieval of HLW disposal package and removal/reinsertion of the operating plug.

They are powered by the HLW shuttle. Power is not available, however, during the cask transfer phases. Furthermore, the HLW casks must provide radiological shielding during the docking phases. This function must be ensured under normal, incident and accident situations. The HLW cask has neutron shielding on account of the nature of the high-level waste It does not perform a confinement function, which is ensured by the HLW disposal package (see section relating to the risk of dispersal in volume III).

The following figure illustrates a HLW cask.

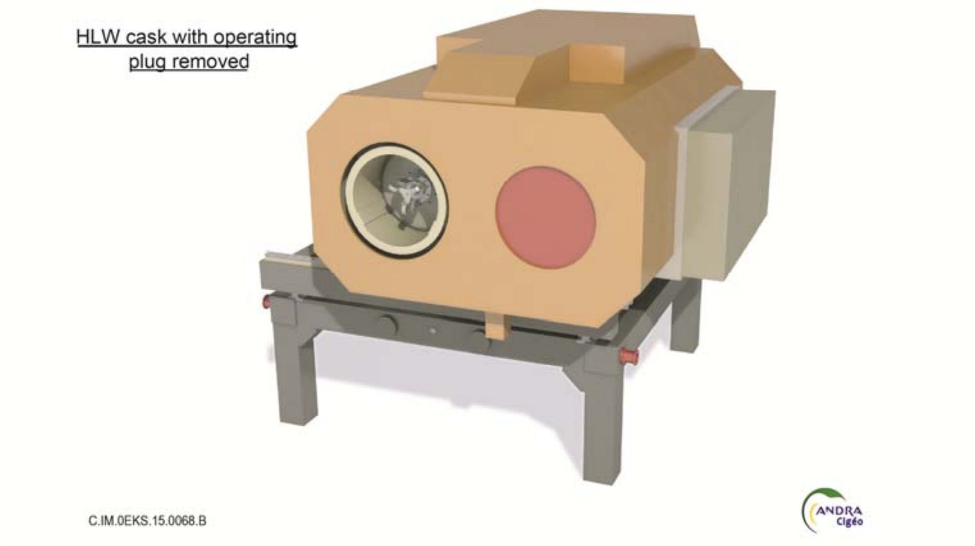

Figure 3.3-22 Diagram of a HLW cask

The characteristics of HLW casks are given in the following table.

Table 3.3-2 Characteristics of HLW casks

Weight of cask	Casks for Ø 606 packages	Casks for Ø 671 packages
Empty weight (kg)	77800	77800
Max. weight (kg)	79900	81200

3.3.10.3 Transfer of the casks at the surface

<u>Inside the cask storage hall</u>, the transfer cycle comprises the following activities:

- transfer of an empty (HLW or ILW-LL) cask to a (HLW or ILW-LL) docking facade;
- positioning of cask against the facade by the docking table;
- loading of disposal package into the cask;
  - ✓ opening of cask and docking facade;
  - ✓ insertion of the package into the cask;
  - ✓ closing of cask and docking facade;
- undocking of cask using the table;
- transfer of full cask to the cask turntable by the low lift machine (MLL);
- cask set-down on the turntable;
- orientation of cask on the turntable;
- transfer of full cask towards the ramp transfer system by the shuttle corresponding to the cask type.

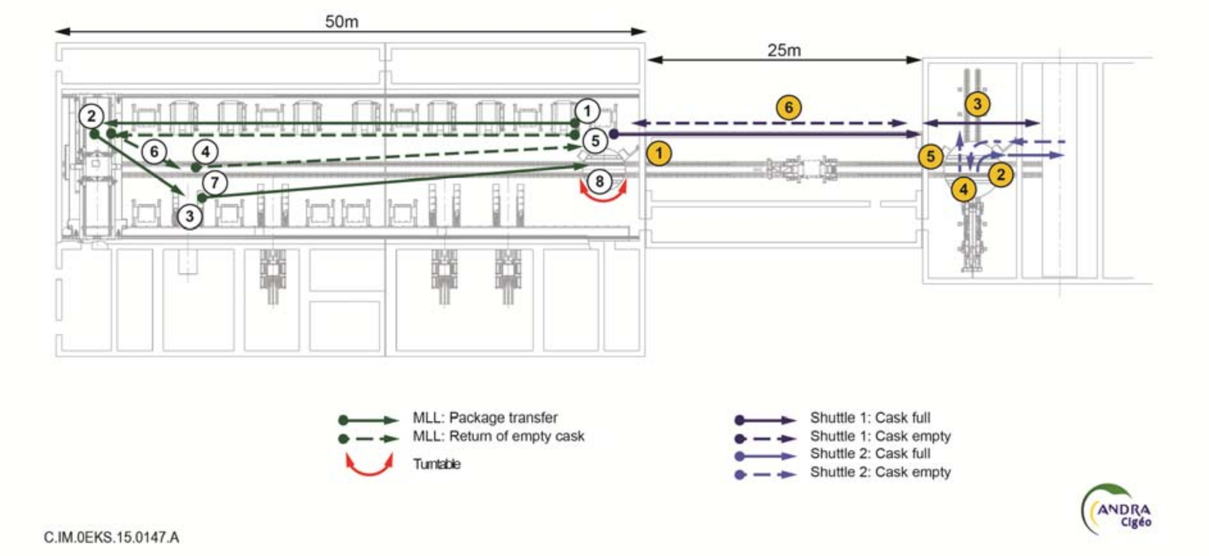

Figure 3.3-23 Diagram of the surface transfer cycle

<u>At the ramp head</u>, the transfer cycle comprises the following activities:

- removal of empty cask from the ramp transfer system by the surface shuttle,
- surface shuttle with empty cask waits in the siding,
- setting-down of full cask on the ramp transfer system by the surface shuttle;
- setting-down of empty cask on the ramp transfer system by the surface shuttle;
- Picking-up of empty cask from the turntable by the surface shuttle for transfer to the cask store.

The figure below shows the principles of management at the ramp head with a transport shuttle.

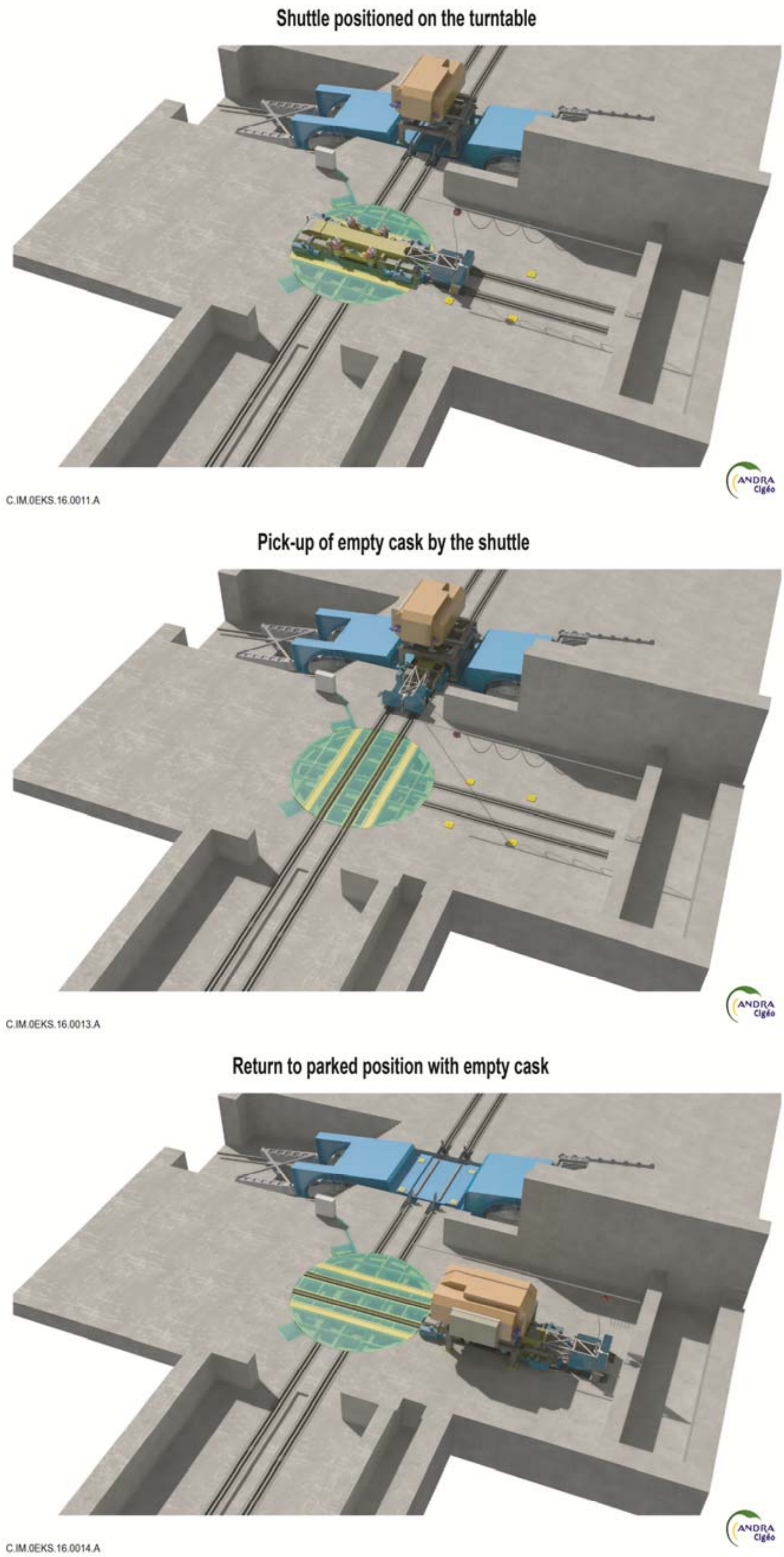

Figure 3.3-24 Principle of management at the ramp head

3.3.11 EP1 surface-level cask management zone

The surface-level zone of EP1 used for managing casks and operating them with packages from the loading room or the underground facility, consists of the following:

- The cask and surface shuttle maintenance and preparation room. This room can, after configuration, be used to perform the operations for potential decontamination of the internal cavity of the casks;
- the cask storage and docking hall consists of:
  - ✓ an ILW-LL and HLW0 cask storage area;
  - ✓ an area containing the four docking facades;
  - ✓ a cask transfer transit area;
  - ✓ the connecting drift within which the transfer shuttles travel between the cask storage and docking area and the ramp head,
  - ✓ the ramp head, the area within which the casks are loaded onto or unloaded from the ramp transfer system.

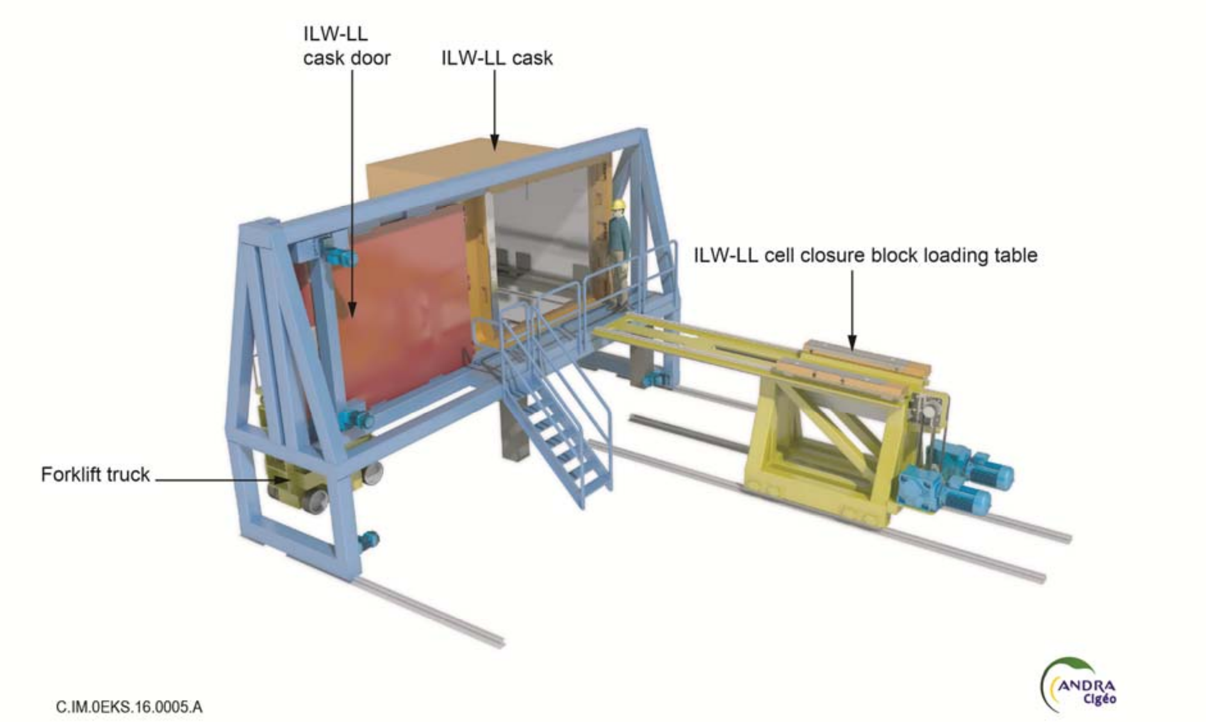

Figure 3.3-25 ILW-LL maintenance station – Maintenance room

The cask storage area houses the HLW and ILW-LL casks, as well as the handling equipment necessary for their transfer between the different zones. The different items of equipment used are presented below.

3.3.11.1 The Low-Lift Machine

The Low-Lift Machine located in the cask storage and docking area handles the casks within the transit zone. It performs part of the handling operations of empty or full casks between the different areas of the hall.

The Low-Lift Machine is fitted with a single, fixed lifting beam, which is integral with the rest of the machine. The interface between this Low-Lift Machine and the HLW and ILW-LL casks is standard for all casks.

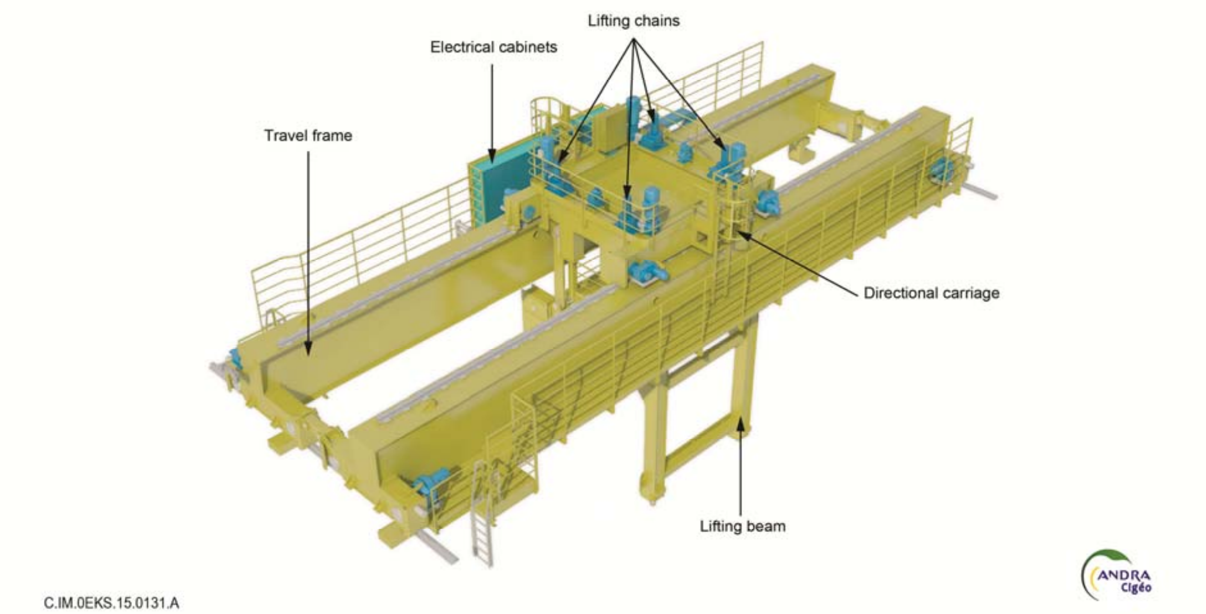

Figure 3.3-26 The Low-Lift Machine

The Low-Lift Machine lifts the casks and moves them just off the ground. Its lift height is mechanically limited by design (~100 mm). All handling operations are therefore performed without ever exceeding the cask qualification heights.

<u>Main characteristics and performance:</u>

- range: 20000 mm;
- Safe working load SWL: 90T;
- Travelling speed:
  - ✓ Low speed: 8m/min;
  - ✓ High speed: 20m/min;
- Trolley speed:
  - ✓ Low speed: 2m/min;
  - ✓ High speed: 20m/min;
- Hoisting speed:
  - ✓ Low speed: 0.20m/min;
  - ✓ High speed: 0.35m/min;

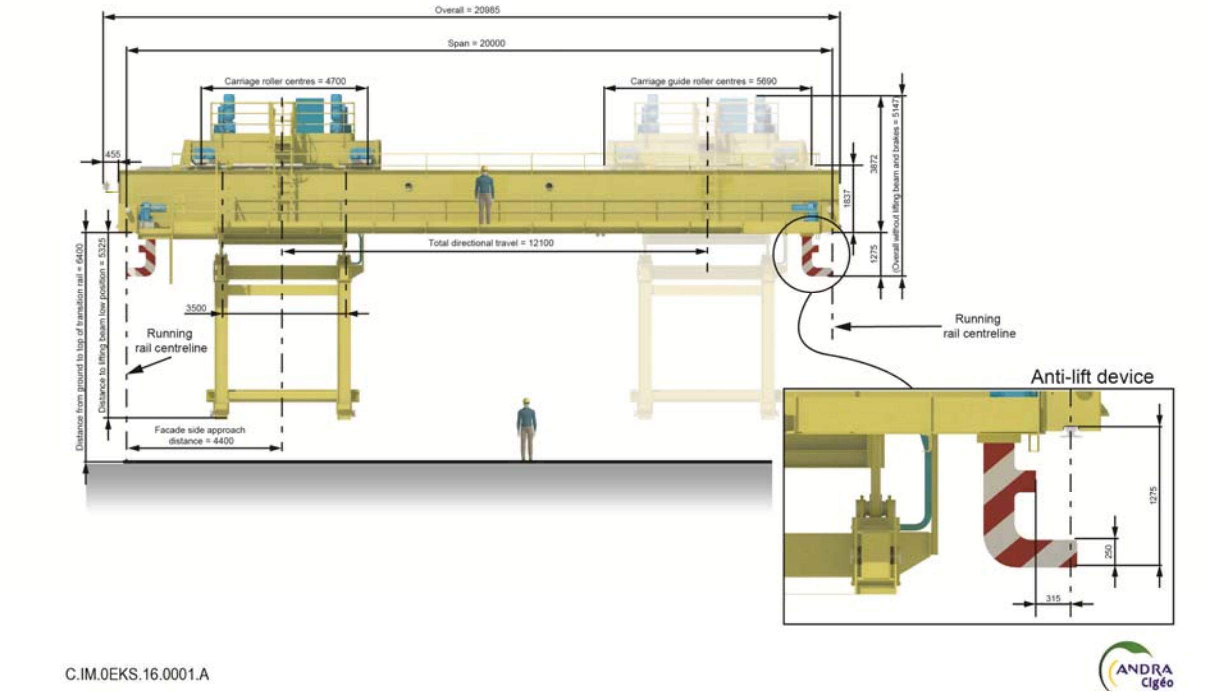

Figure 3.3-27 Low-Lift Machine (MLL) – anti-lift device

3.3.11.2 ILW-LL docking facades

The surface-level ILW-LL docking facades form the interface between the cask and the loading rooms. They enable the insertion of ILW-LL disposal packages into the ILW-LL transfer casks while ensuring continuity of containment and radiation protection.

Docking of ILW-LL casks is performed by the following items of equipment:

- The docking table is the item of equipment on which the Low-Lift Machine sets down the cask. This docking table serves to accurately position the cask relative to the facade for docking purposes;
- The surface-level docking facade controls the opening between the loading room and the cask storage and docking hall:
  - ✓ in the absence of the cask, it ensures the separation of the two spaces in compliance with the zoning requirements;
  - ✓ in the presence of a cask docked and locked to the facade, it safeguards the opening of the doors and guarantees the continuity of zoning when the cask and facade doors are open. Once the package is placed inside the cask, the doors are closed again. The cask seal is tested, the cask is released from the facade and transferred by the Low-Lift Machine.

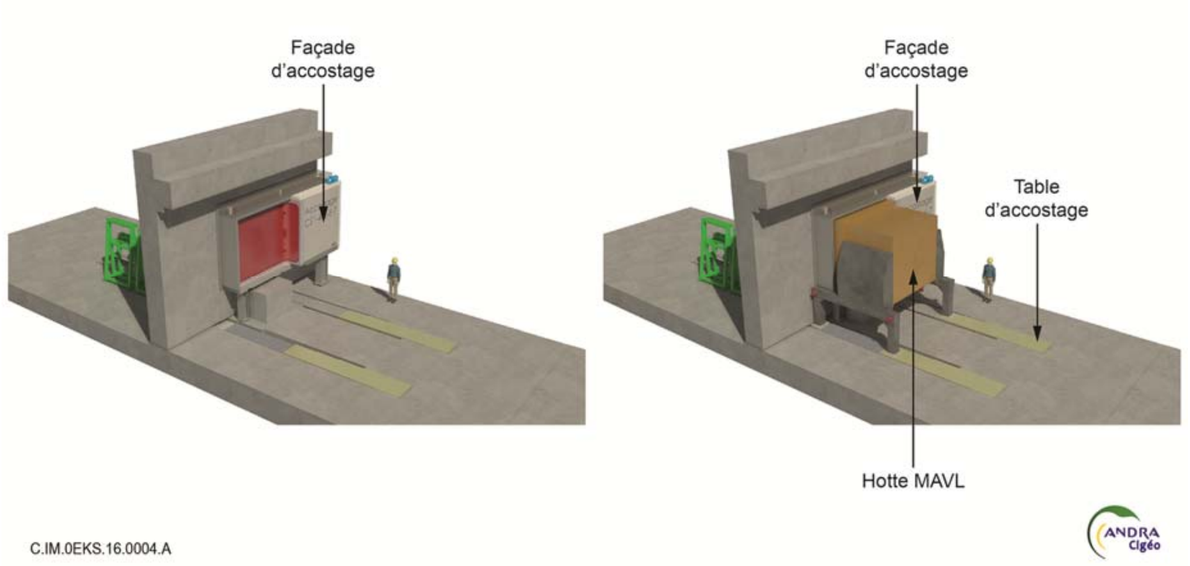

Figure 3.3-28 Surface-level ILW-LL docking facade

The docking facade comprises:

- a reinforced concrete wall ensuring radiological shielding and confinement of the rooms. It contains the docking facade frame;
- a mechanical part fitted in the frame performing the docking function (opening/closing of cask and loading room doors). It provides radiological shielding and confinement.

There are three ILW-LL docking facades, one per loading room.

For inserting the packages into the casks, each docking facade is supplemented by a loading table on the loading room side.

3.3.11.3 HLW docking facades

The surface-level HLW docking facades form the interface between the cask and the loading room for both package diameters. They enable the insertion of the HLW disposal packages into the transfer casks.

Docking of the HLW0 casks is performed by the following equipment:

- the docking table is the equipment on which the Low-Lift Machine sets down the cask. This table serves to accurately position the cask on the docking facade;
- the surface-level docking facade controls the opening between the loading room and the cask storage and docking hall:
- the HLW docking facade comprises a plug. The cask, with its grippers and motor drives performs the following operations:
  - ✓ removing the radiation protection plug;
  - ✓ positioning the package cavity ;
  - ✓ inserting the disposal package into the cask;
  - ✓ placing in the plug cavity position;
  - ✓ Refitting the radiation protection plug.

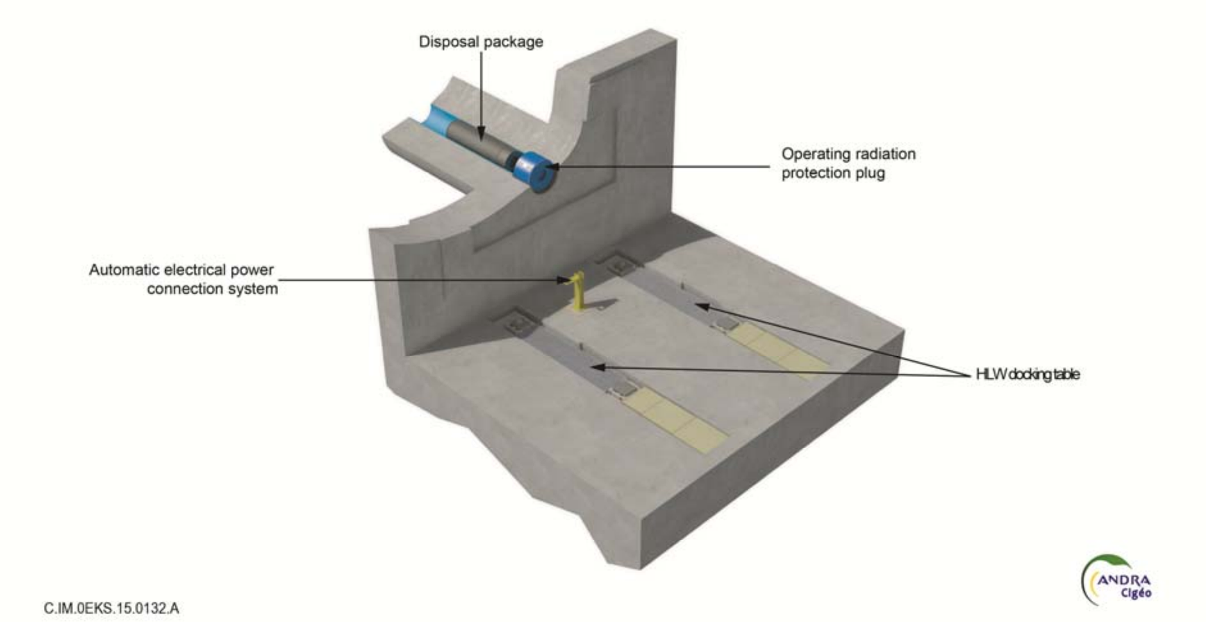

Figure 3.3-29 Surface-level HLW docking facade

3.3.11.4 Surface shuttles

The shuttles serve to transfer casks between the different surface zones:

- transfer of casks to maintenance workshop;
- transfer of full casks to the ramp transfer system;
- transfer of empty casks to the pick-up area.

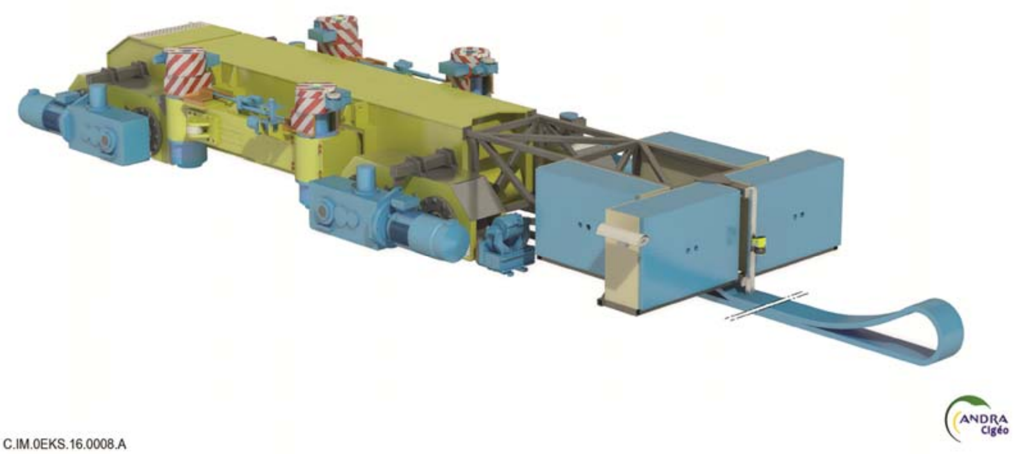

Figure 3.3-30 Ramp transfer system loading shuttle

The shuttles are under-travelling and designed to pass beneath both HLW and ILW-LL casks. As the zones they cover are of limited length, they can be powered via drag chains.

They have an XY table, which compensates for positioning inaccuracy and ensures precise cask pick-up or set-down. The cask lifting device (4 lifting points) is mounted on the XY table. It enables a limited lifting motion in the same way as the Low-Lift Machine. In this way the casks travel close to the ground. At this stage of the project, the chosen shuttle characteristics and performances are as follows:

- Travelling speed:
  - ✓ Very low speed: 0.6 m/min;
  - ✓ Low speed: 8 m/min;
  - ✓ High speed: 30 m/min;
- Acceleration: 0.1 m/s^2;
- Safe working load SWL: 90T (bounding weight of a loaded ILW-LL or HLW cask);
- Raise time: 150 s;
- Raise height: 120 mm,
- Cask adjustment range in Y direction (perpendicular to the rail): ± 20 mm;
- Estimated weight: 37,000 kg.

3.3.11.5 Running tracks

At this stage, the choice of design assumptions and choices are as follows:

- Type MRS 125 running rails,
- a spacing between inside faces of 1435mm (standard UIC spacing);
- continuous rails in the main section;
- gaps of a few centimetres at most at discontinuities (turntables, air locks and ramp transfer).

3.3.11.6 Turntables

A first turntable is located at the entrance to the ramp head connecting drift. It turns the casks to 0°, 90° or 180°, either on the way to or back from the ramp. This turntable can be used to orient the casks, but is not able to rotate the shuttles. A second turntable, located at the ramp head, enables cask loading/unloading operations to be performed in a way that is compatible with the transfer system cycle times. This larger diameter turntable, which is if the same design as the cask turntable, can be used to turn the shuttles listed here:

- The shuttle (shuttle C) transporting the empty cask onto a siding track,
- The shuttle (shuttle B) transporting the full cask to the ramp transfer.

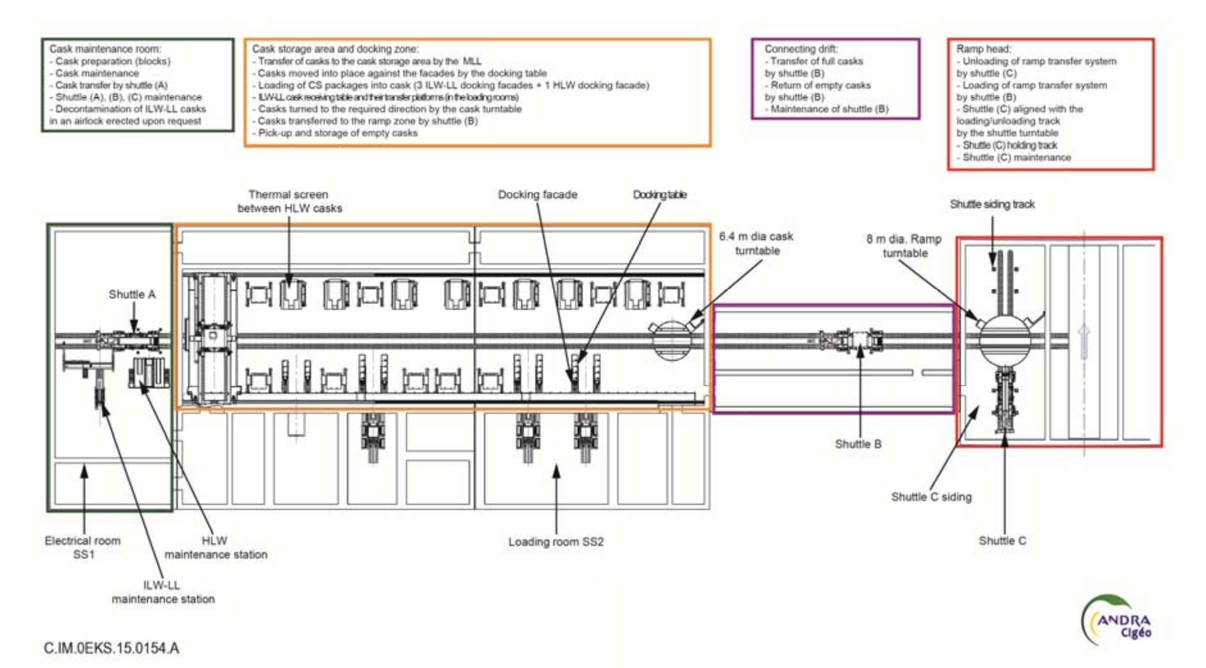

Figure 3.3-31 Surface-level turntables

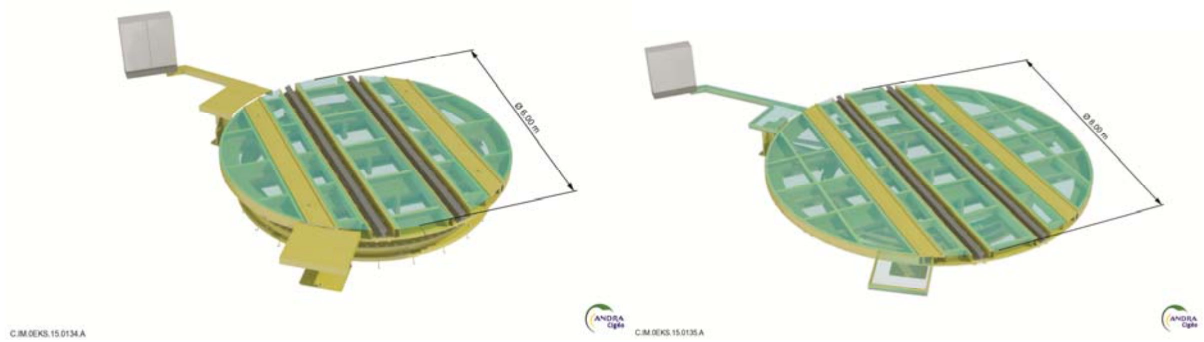

Figure 3.3-32 Surface-level turntables – shuttles and casks

3.3.12 Surface facility auxiliary systems

3.3.12.1 Electricity

At this stage, two HV range A (HVA) loops are provided to supply power to the facility:

- A "Northern" loop supplying the sub-stations located to the north of the facility;
- A "Southern" loop supplying the sub-stations located to the south of the facility.

3.3.12.2 Ventilation

The ventilation consists of an air supply system and an air removal system. These two systems are fitted with redundant fans (normal and backup) ensuring the continuity of the function in the event of a fan failure. The ventilation system power supply is also redundant and emergency-supplied (uninterruptible power supply (UPS)).

A diagram of the ventilation principles of the surface nuclear installations is presented below.

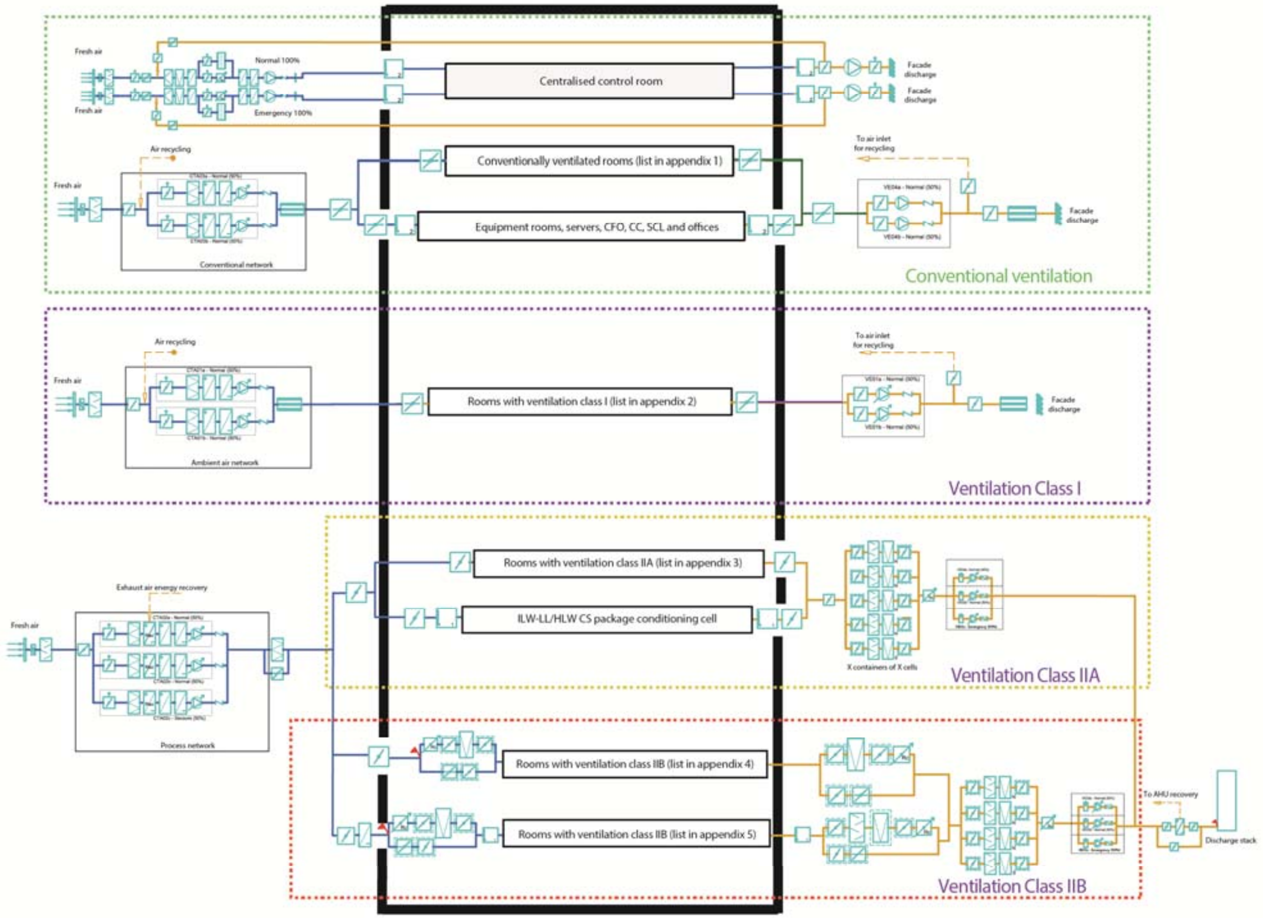

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Figure 3.3-33 Principles of ventilation

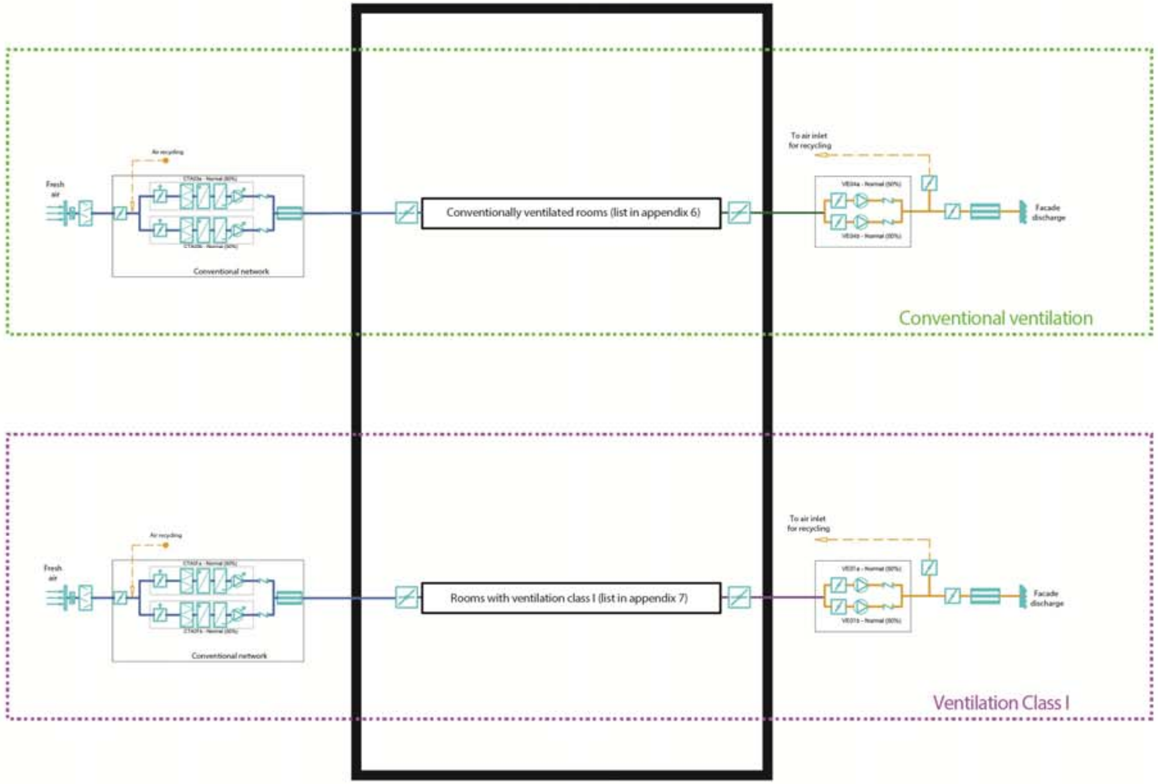

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Figure 3.3-34 Principles of ventilation of the surface nuclear buildings

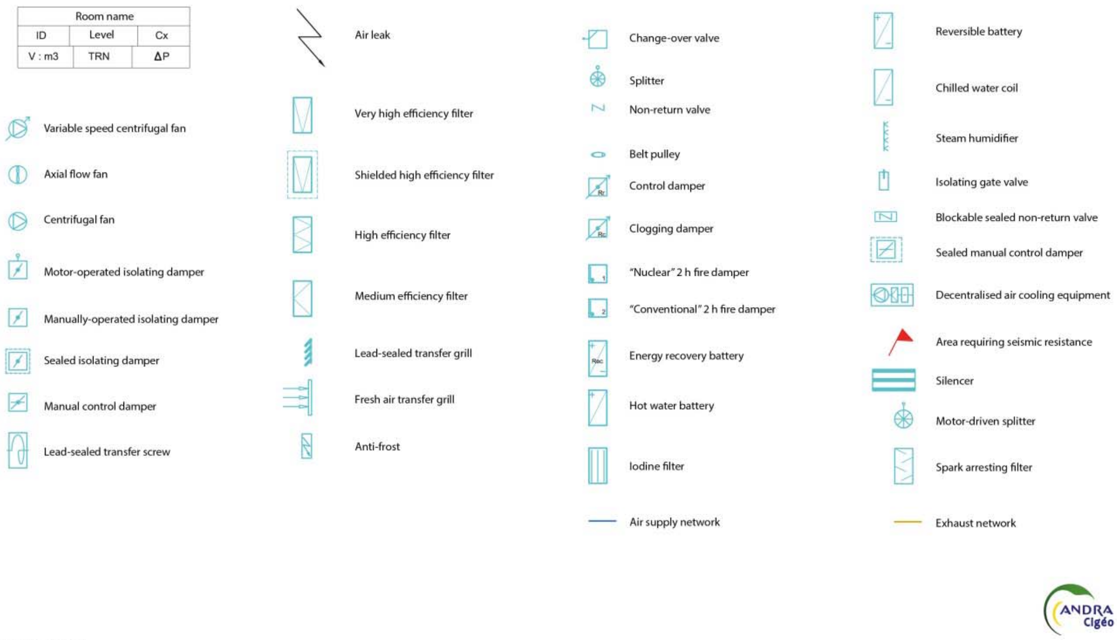

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Figure 3.3-35 Principles of ventilation of the surface nuclear buildings key of symbols for the previous figures

List of rooms with conventional ventilation (nuclear building):

- personnel, equipment and process circulation;
- store;
- archives;
- supply air room (nuclear ventilation);
- pallet and basket disposal container reception halls;
- forward, buffer and crane maintenance areas;
- truck, personnel and equipment airlock;
- waste sorting;
- rest room;
- PPE store;
- pallet store.

List of rooms with ventilation class I (nuclear building):

- personnel, equipment circulation;
- visitor room;
- transport container halls and reception;
- Bridge crane maintenance area;
- transfer cart pit;
- transfer cart transfer carriage;
- transfer cart siding;
- transport container support and frame reconfiguration;
- preparation room;
- filling material supply room;
- grouting binder production room;
- rear zone;
- process, personnel and equipment airlock;
- empty and full cask storage area;
- hot store

- equipment room;
- office;
- Bridge crane rear zone;
- handling equipment servicing and connecting drift.

List of rooms with ventilation class IIA (nuclear building):

- buffers and doubtful and active effluent;
- NC container treatment
- cart docking;
- personnel, equipment and process circulation;
- air lock
- NC primary package buffer zone (12 spaces);
- nuclear ventilation filtration room;
- HLW pallet and basket contamination inspection cell
- forward zone (C5 inspection);
- primary package in non-prepared disposal package buffer zone;
- filling material injection room;
- rear zone;
- Bridge crane rear zone;
- hot workshop;
- C7 inspection cell;
- HLW/ILW-LL cask loading;
- cask descent room;
- equipment room.

List of rooms with ventilation class IIB (nuclear building):

- personnel and equipment airlock;
- rear zone;
- rear zone (conditioning cell);
- rear zone (disposal package loading station);
- cart rear zone.

list of rooms with type IIIB ventilation (nuclear building):

- cell for inserting primary packages into disposal packages;
- cell for loading primary packages into disposal packages + inspection C5;
- unloading cell;
- Bridge crane rear zone;
- reconditioning + inspection C5 cell ;
- disposal package loading station;
- HLW container unloading cell.

List of rooms with conventional ventilation (ramp head building):

- ramp ventilation room;
- personnel and equipment circulation;
- ramp transfer electrical rooms.

List of rooms with ventilation class I (ramp head building):

- airlock (process);
- two-track transfer carriage airlock;
- ramp head connecting corridor (future connection to EP2);
- ramp head connecting drift (future connection to EP2);
- ramp head connecting corridor (connection to EP1);
- ramp head connecting drift (connection to EP1);
- Machinery/maintenance pit/tension pit.

Regarding the ventilation control system, one PLC will be provided per channel. Together with its cabinet, it constitutes an autonomous and redundant assembly for automatically switching to the backup channel in the event of failure or loss of the active channel.

The means of supervision and, if necessary, operation of the nuclear ventilation system are located in the centralised control room of building EP1.

3.3.12.3 Nuclear process instrumentation and control system

The instrumentation and control functional unit comprises the following sub-assemblies:

- the equipment necessary for nuclear process instrumentation and control,
- embedded or non-embedded video monitoring, associated with operations,
- real-time geolocation tracking of packages.

The instrumentation and control system architecture is presented in section 3.6.3

3.3.12.4 Communications and Security Systems

The functional units (EP) are as follows:

- the DP (Special measures) functional unit related to access control, intrusion detection, surveillance (roundsman system) and building video-surveillance;
- the SSP (Personnel safety) functional unit related to the safety of personnel in controlled areas;
- the VDI (Voice, Data, Image) functional unit related to telephone, inter phone, video broadcasting network (television, site information) radio-communication;
- the BMS (Building Management System) functional unit managing the fluids and utilities, and the LV electricity of building EP1;
- the GTC (centralised technical management system) functional unit, related to the acquisition of critical data (alarms, events);
- the GTE (Power Management System) functional unit related to the surveillance and operational maintenance of the electrical systems;
- the RP (Radio Protection) functional unit for ambient radiological monitoring, the monitoring of gaseous and liquid discharge, the monitoring of atmospheric discharge from exhaust stacks and operational dosimetry;
- the SSI (Fire control system) functional unit for the fire detection and safety of building EP1;
- the VN (Nuclear ventilation) functional unit;
- the MCO (Through-life support) functional unit using computer-aided maintenance management (CAMM).

Inter-functional unit links are established to establish control loops between:

- the SSI (Fire control system) and the nuclear ventilation system and its own control system (EF VN);
- the SSI and the mechanical equipment of the various process units via the Instrumentation and control functional unit. Typically detection of a fire (SSI functional unit) will cause the activation of the control systems to place the items of equipment concerned in the fallback position or the safe shutdown state;
- The radiation protection system (EF RP) and nuclear ventilation system.

Information is exchanged via interoperability modules enabling the transfer of the data to be exchanged between the systems concerned (SSI, VN, RP), each with their own communication network (independent physical support).

3.4 The underground facility

3.4.1 Design principles choice of underground architecture

3.4.1.1 Main requirements for the design of the underground facility

The design of the disposal centre's underground facility is based on a strategy of phased development in accordance with the Cigeo operating master plan (PDE). The design of the initial structures (phase T1) takes account of the better knowledge and operating experience feedback available at the time they are constructed. This first phase is designed so as not to compromise the development of the later repository construction phases (TU phase).

The architecture is designed on the basis of an inventory of waste packages and a delivery schedule associated with the PIGD (VD) Industrial Waste Package Management Programme (at this stage). It can be adapted to accommodate changes in the inventory as a result of decisions taken in the future in terms of industrial or energy policy: new types of waste, increased volumes of waste, or reorientation towards deep disposal of waste for which the acceptability in shallow disposal solutions is not guaranteed. The safety options adopted are compatible with these possible future decisions.

3.4.1.2 The underground architecture solution

According to the development time sequence, the underground architecture will include the following underground structures:

- surface-to-bottom connections linking the surface facilities to the logistical support zones;
- two separate underground logistical support zones, one for operation and the other for the construction works;
- Organisation of the repository into three main repository zones (ILW-LL, HLW0, HLW1/HLW2):
  - ✓ the ILW-LL zone forms a single disposal section (a section is a grouping of dead-end cells and access drifts;
  - ✓ the HLW0 zone;
  - ✓ the HLW1/HLW2 zone consists of six sections.
- ILW-LL and HLW cells grouped in sections;
- cells designed to be incorporated in the clay formation on the basis of safety, technical and economic choices. The main safety and technical selection criteria are the preservation of the characteristics of the medium and the design of structures that are the basis of the long term safety performance, the ability to ensure safety and safe operation, as well as reversibility (justified by experience and studies, tests conducted in the Meuse/Haute-Marne Underground Research Laboratory),
- The design principles of progressive deployment ensure safety and security with a physical separation between the conventional construction work zones and the nuclear operating zones, which reduces the risks associated with co-activity (separation of personnel flows, utilities, support functions etc.)

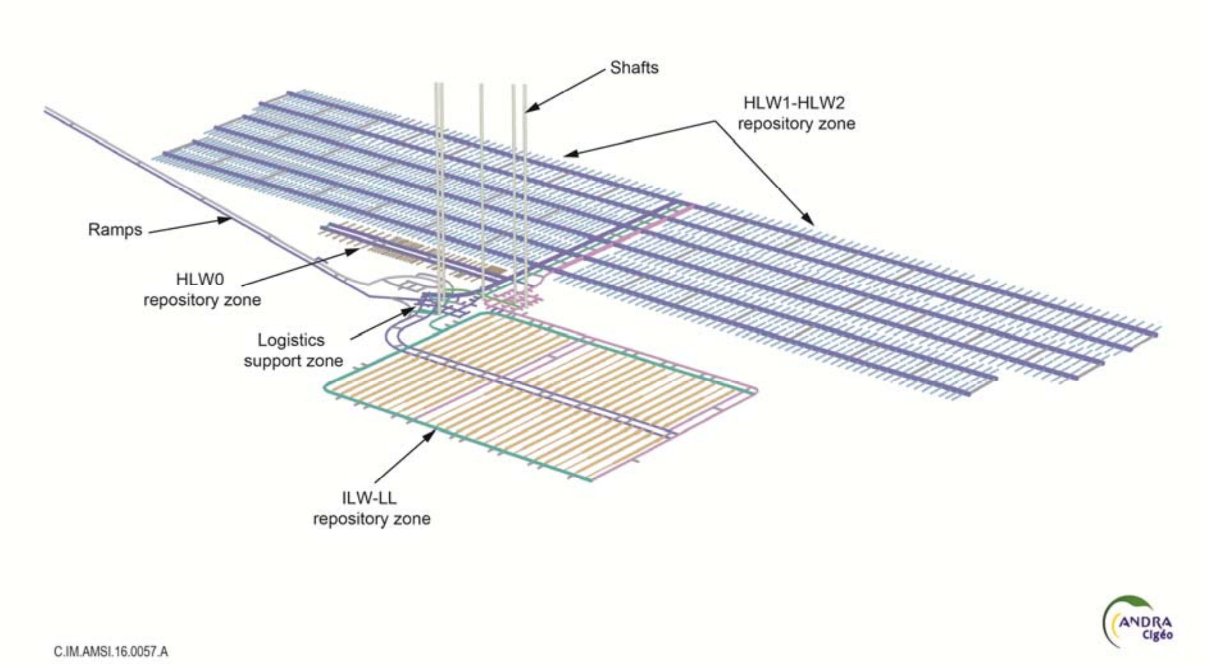

Figure 3.4-1 Cigeo underground facility

3.4.2 Progressive Development of the Repository

The underground facility is constructed gradually throughout the operation of the repository over a one-hundred-year period. An initial construction and operating phase (corresponding approximately to the first fifteen years) will be followed later by further implementation phases. The design takes account of this development and focuses initially on the first phase while ensuring compatibility with the later phases.

3.4.2.1 The 1st construction and operating phase

The initial structures constructed meet the operating needs of the first cells of the ILW-LL zone and of the HLW0 zone, the first phase of construction. Phase 1 includes the construction of the surface-to-bottom connections by ramps and shafts, the construction and operating logistics support zones and the construction of the first cells of the ILW-LL disposal section and the HLW0 repository zone.

An industrial pilot phase is planned at the start-up of Cigeo. It will start during the initial construction and continue at the start of repository operation. It includes “inactive” operations, such as tests on installed equipment, as well as “active” operations, in other words on waste packages. All the tests, demonstrator set-up (e.g. of seals or cells), operating and monitoring operations necessary for the smooth start of Cigeo and the operation ramp-up are carried out during this period.

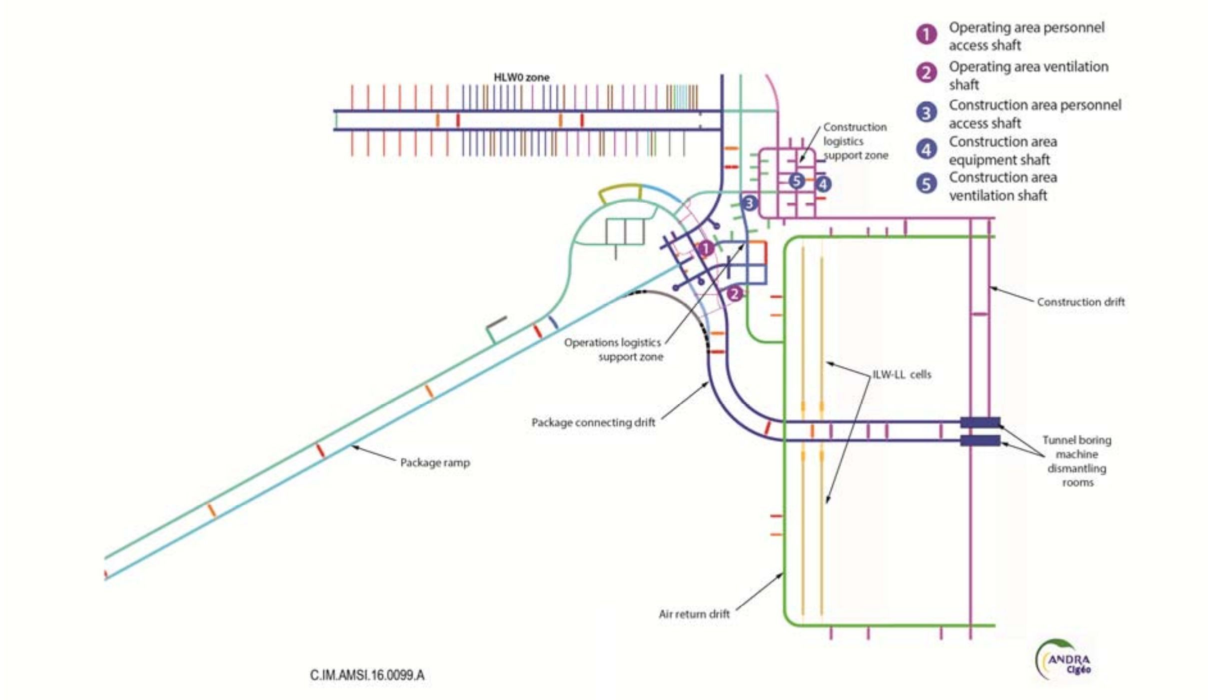

Figure 3.4-2 Construction phase 1 (T1)

3.4.2.2 Later disposal phases

The incremental development of the repository will then continue with the construction and operation of the ILW-LL repository zone. It reflects the continuous, regular and prudent nature of the sequencing of construction operations for the disposal facility throughout its operating life It enables the incorporation within the future construction phases of any improvements which may have been made possible over the one hundred year duration of the project by scientific and technical advances, as well as by feedback with the aim of achieving technical and economic optimisation of the design as well as for achieving continuous improvement (as defined by the order of 7 February 2012) of safety provisions.

After operation, the repository zones will be gradually closed according to the choices made under the Cigeo operational master plan (see PDE).

3.5 Description of the underground facility and package transfer processes

3.5.1 Surface-to-bottom connections

3.5.1.1 The main surface-to-bottom connection design requirements

The surface-to-bottom connections are designed to meet design, operating and limited environmental impact principles,

- The impact of the surface-to-bottom connections on aquifers is limited. The corresponding requirements are as follows:
  - ✓ deep aquifers and limitation of communication between aquifers: measures taken to prevent communication between aquifers during operation and post-closure,
  - ✓ surface aquifers (groundwater): groundwater leakage from the Tithonian layer of 50l/h under the foundation (via the surface-bottom connection),
  - ✓ deep aquifers: treatment of dewatering water from the Oxfordian layer according to the flow at the water generating levels. Drainage of the Oxfordian layer to prevent run-off in the Callovo-Oxfordian layer: water flow rate between the Oxfordian and Callovo-Oxfordian layers limited to 20l/h.

- the shafts and ramps are grouped at the bottom (to meet the post-closure safety functions (see DOS-AF Volume II, chapter 3),
- the shafts and ramps connect the surface facilities to the logistical support zones, they are spread over two zones:
  - ✓ the ramp zone comprises a package transfer ramp and a service ramp,
  - ✓ the shaft zone comprises five shafts (two for operation and three for construction),
- the surface-to-bottom connections are constructed during the first phase of construction,
- these structures are envisaged to have a service life of 150 years,

3.5.2 Surface-bottom connections within the "Ramp" zone

The "Ramp" zone facilities are linked to the underground facility via two parallel, inclined ramps with a slope of the order of 10 to 15 % (12% at the basic engineering design phase):

- **the waste package transfer ramp** serves to transfer waste packages to the disposal structures within the underground facility;
- **the service ramp** serves operating functions other than waste package transfer (evacuation/emergency, maintenance, materials/equipment delivery).

The ramps consist of three sections: the head, the body and the bottom.

1. The head of the package transfer ramp is connected to the surface nuclear facilities. Upstream of the tunnel headwall, a group of buildings will cover most of the tramp head, with the exception of the final 30 metres which form the covered trench between the buildings and the headwall,
2. The ramps are excavated using a full-face tunnel boring machine. They are sealed in the Barrois limestone. The bodies of the two ramps are excavated in parallel using two full-face tunnel boring machines capable of excavating a tunnel of approximately ten metres diameter. A seal is formed at the base of this limestone layer. Construction measures are taken in the Oxfordian limestone layer to limit water flow. A seal is formed at the base of the Oxfordian limestone (at the top of the clay rock);
3. A cross cut is provided at the bottom of the ramp for dewatering. The boring machines continue digging the connecting drifts towards the ILW-LL disposal section.

The two ramps, which are fifty metres apart, are connected by cross cuts every 400 metres, in order to allow intervention in emergency situations (evacuation, rescue).

The effective diameter of the ramps meets the installation and operating of the ramp transfer and cask transfer (at this stage the effective diameter is of the order of 8.4 m).

At the basic engineering design stage, the liner consists of concrete liner segments and two-layer[47] compressible liner segments within the clay layers. Various solutions are currently under examination for the compressible materials at the liner segment/clay rock interface. The use of two-layer compressible liner segments is scheduled to be tested at the end of 2016 / beginning of 2017, in the Centre Meuse/Haute-Marne Underground Research Laboratory.

Throughout the construction of the underground works prior to the operation of the repository (T1), the ramps are used exclusively for construction-related flows. The ventilation and safety are specific to this phase of the works.

[47] Two-layer liner segments comprise an additional layer of compressible material on the outer face of the concrete layer, to allow partial convergence of the rock (and reduce the loads supported).

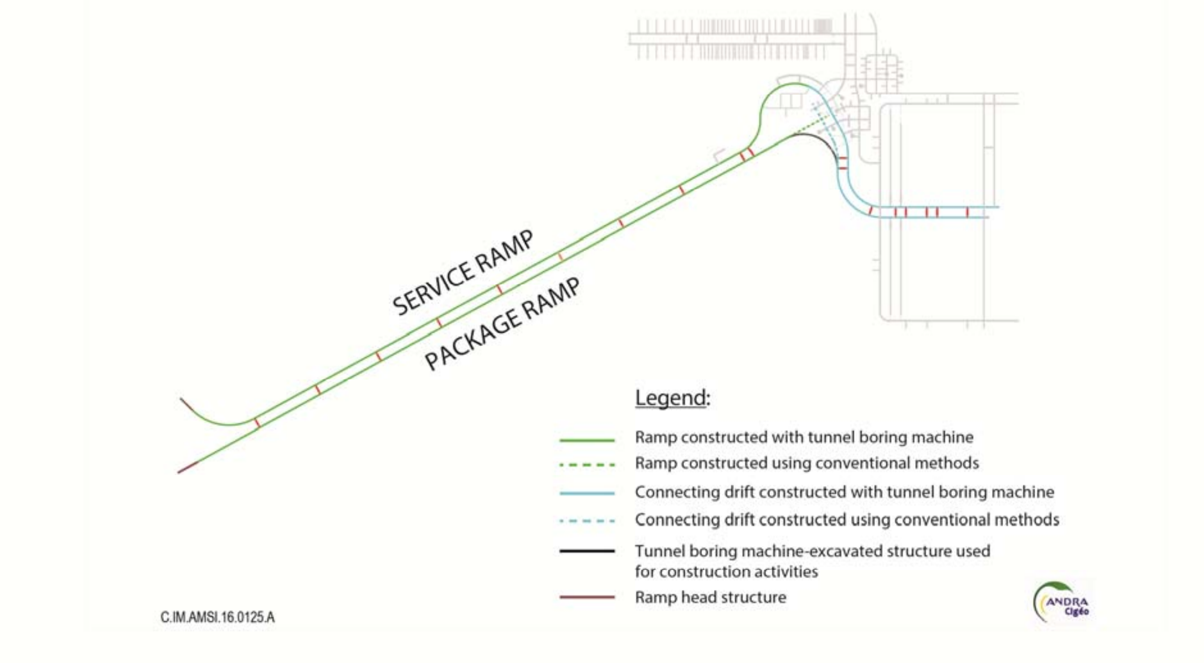

Figure 3.5-1 Package transfer and service ramps (view at the basic engineering design stage)

During the operating phase, full-section bottom-up ventilation is provided It is ensured by an air supply from the ventilation plenum in the logistical support zone. A ventilation scheme, including the operation of the ramps is presented in chapter3.5.13.2. At the time of final closure of the repository, the ramps are backfilled and a seal is formed in each ramp at the top of the clay formation (see DOS-AF Volume II, Chapter 3).

3.5.3 Inclined transfer system in the ramp

3.5.3.1 Ramp transfer system footprint

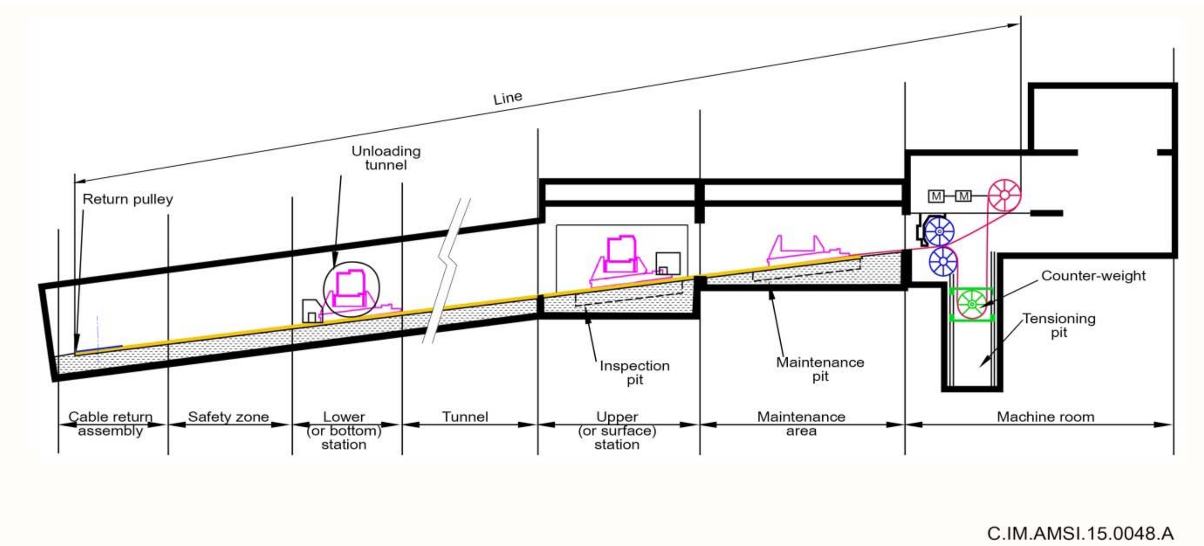

Figure 3.5-2 Diagram of the ramp transfer system footprint

The ramp transfer system extends over 8 zones (from upstream to downstream):

- the zone between the outside and the machine room;
- the machine room;
- the servicing and maintenance room;
- the upper (or surface) station;
- the package transfer ramp tunnel;
- the lower (or bottom) station;
- the safety zone;
- the cable return assembly zone.

3.5.3.2 Main functions and characteristics of the ramp transfer system

The main function of the ramp transfer system is to transfer casks in the straight ramped waste package transfer tunnel between the surface and the bottom, to the logistical support zone (down and up).

The disposal package transfer operation between the surface and underground facilities comprises the following three stages:

- loading / unloading transfer casks in the upper station;
- transfer in the ramp tunnel;
- loading / unloading transfer casks in the lower station.

The loading / unloading operations in the upper and lower stations represent “sensitive” operations and interfaces and are automated, with supervision and coordination performed at a higher level.

During the disposal operations, the flow of packages is exclusively from the surface to the bottom. This means that during package transfer from the surface to the bottom, the ramp transfer system carries a transfer cask containing a disposal package, while when returning to the surface, it carries an empty cask.

During the disposal package retrieval operations, the lower station of the ramp transfer system handles a transfer cask containing a package.

The main characteristics are as follows:

Main characteristics of the ramp transfer system (at the current stage) – operating range	Ramp transfer system operating conditions
Height difference: approximately 500m, Slope: 12% +/- 1%; Length: approximately 4 200 m; Weight of transfer casks: 130 tonnes max.; Target availability: 98.5%; Total operating period of the order of 120 years with intermediate renovation; Return cycle time: 1 hour max., excluding cask loading / unloading time.	Vehicle speed: 2.55 m/s; Acceleration / Deceleration: 0,05/0.1 m/s2; Slope: 12.06 %; Max. total weight of vehicle + load: 80 + 130 = 210 t.

3.5.3.3 Description and principle of operation of the ramp transfer system (sheaving)

The system adopted is a cable-based transport system with a “vehicle” running on rails. The transfer vehicle is driven by two pulleys simultaneously rotating in opposite directions and tension is ensured by two tensioning pulleys arranged symmetrically in the upper station The principle of the cable loop sheaving system is shown in the figure below.

The sheave is situated at the level of the vehicle by means of “synchronisation” pulleys.

Under normal operation, the two drive pulleys turn together, as well as the return pulleys located in the lower station. There is therefore no movement of the vehicle's synchronisation pulleys under normal operation.

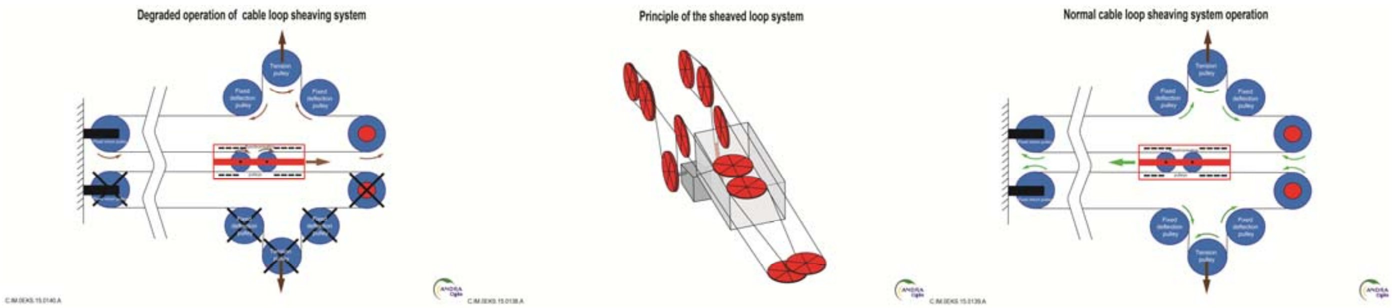

Figure 3.5-3 *Principle of operation and operating situations of the cable loop sheaving system*

Under partial operation, i.e. In the event of the failure of an element on the loop preventing the rotation of one pulley, all the pulleys situated on the same side as the affected pulley will stop turning, causing the cable to be immobilised on that side. However, the side remaining in operation is able to bring the vehicle home at half speed. The synchronisation pulleys begin to rotate in the same direction under the action of the cable tension, thus enabling the cask to be returned to the station.

3.5.3.4 Description of components and equipment

Upper (ramp head) station layout

The loading/unloading zone is the vehicle stopping point opposite the surface shuttle cask delivery and removal locations.

The safety zone is located between the loading/unloading zone and the maintenance area. With a length of approximately 4 m, it is of sufficient length to enable the vehicle to come to a standstill in the event that it continues beyond the upper station stop point.

The maintenance area is intended for carrying out vehicle maintenance operations outside the operating periods. An inspection pit is provided for carrying out certain routine maintenance operations on the underside of the vehicle. This zone is separated from the standard section of the tunnel by a sliding door which only allows the passage of four cable strands while ensuring partitioning between zones.

The machine area contains the cable drive and tensioning equipment. A workshop located next to the drive mechanisms in which are stored all the fixed or mobile equipment necessary for maintaining the ramp transfer system components.

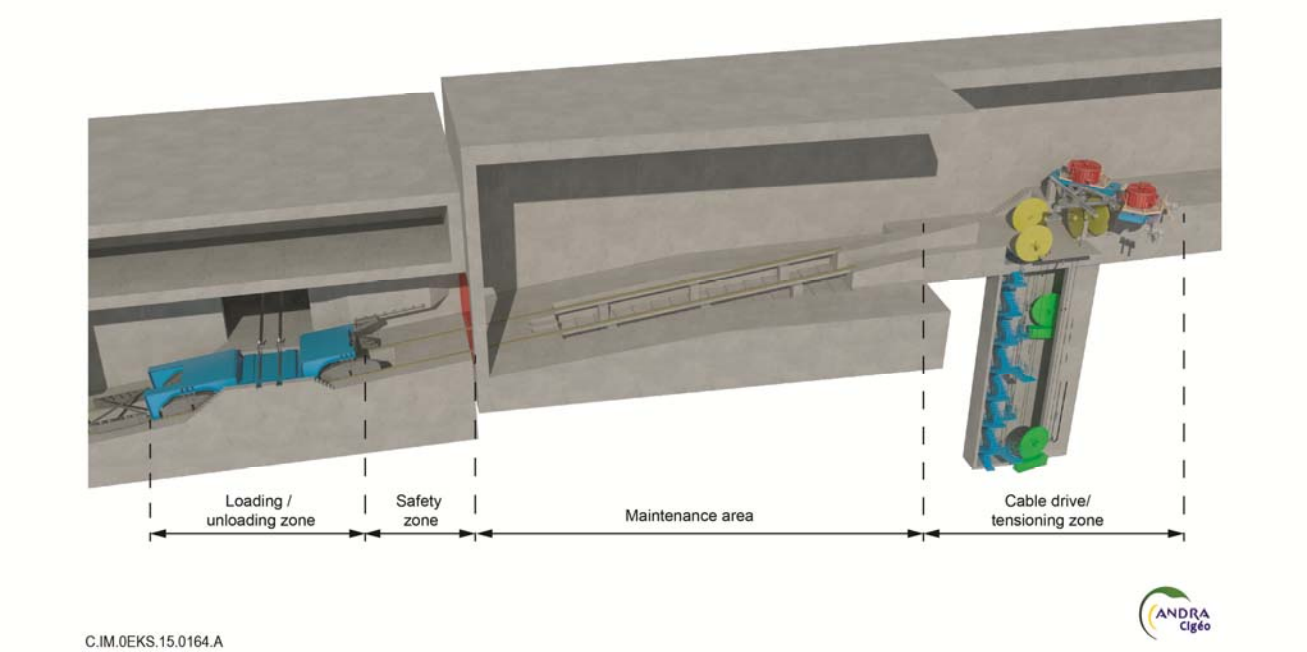

Figure 3.5-4 Upper station layout

Ramp standard section layout

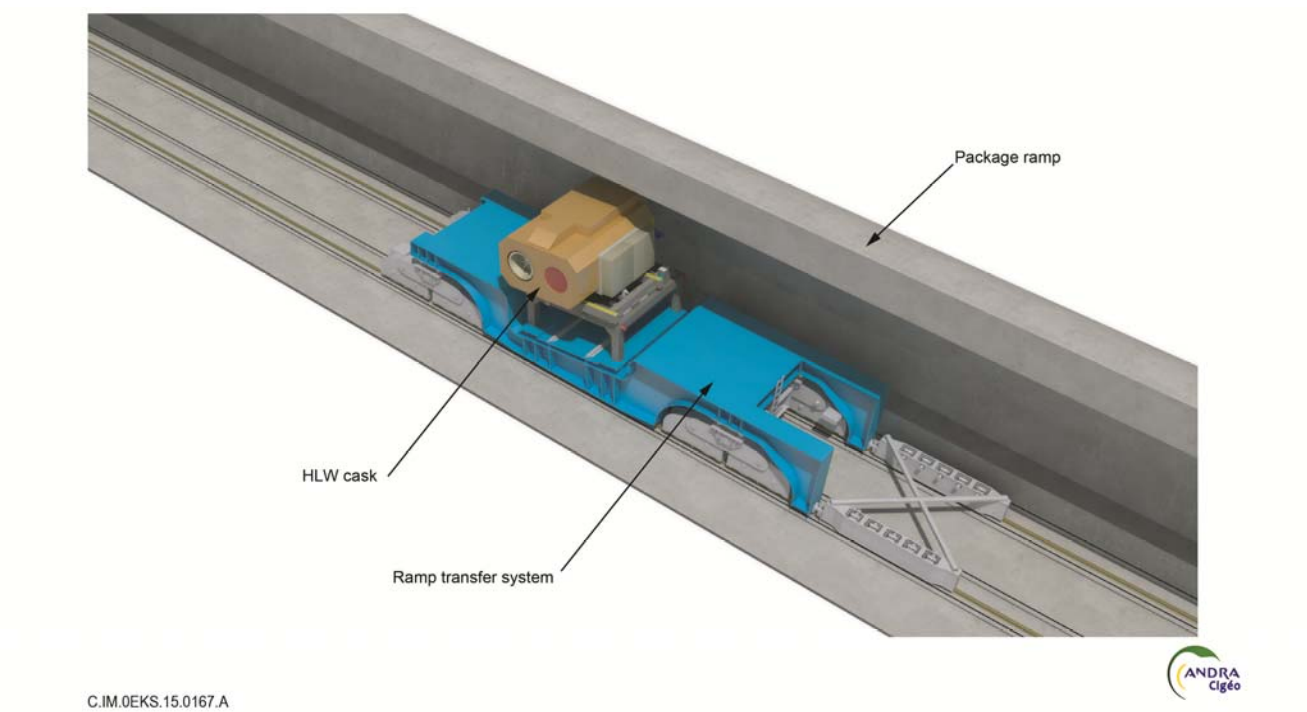

Figure 3.5-5 Package transfer tunnel of the ramp layout (standard section)

The ramp contains a straight length of track from one end to the other without crossings or bends. It is attached to an invert which is itself attached to the ramp tunnel. Part of the networks necessary for ensuring the links between the upper and lower stations run in the invert.

The ramp track width is compatible with the vehicle dimensions. It consists of two parallel MRS 87A type rails, with a flat, stubby profile, attached to the civil engineering structure at 80 cm intervals.

In parallel with this ramp, a second, service, ramp will be constructed, giving access to the package transfer ramp installations for repair of inspection as required. Cross cuts are also provided between these two ramps at 400 m intervals. This access will be regulated and linked to the operation of the ramp transfer system.

<u>Lower (at the bottom of the ramp) station layout</u>

As in the upper station, the lower station has a loading/unloading area with the same equipment and the same functions.

The safety zone, approximately 10 m long, enables the vehicle to be halted by the buffers at the end of the track in the event of arrival at excessive speed or malfunction on the other braking systems.

Finally, the cable return zone consists of deflection rollers located upstream of the two return pulleys attached to a welded metal frame.

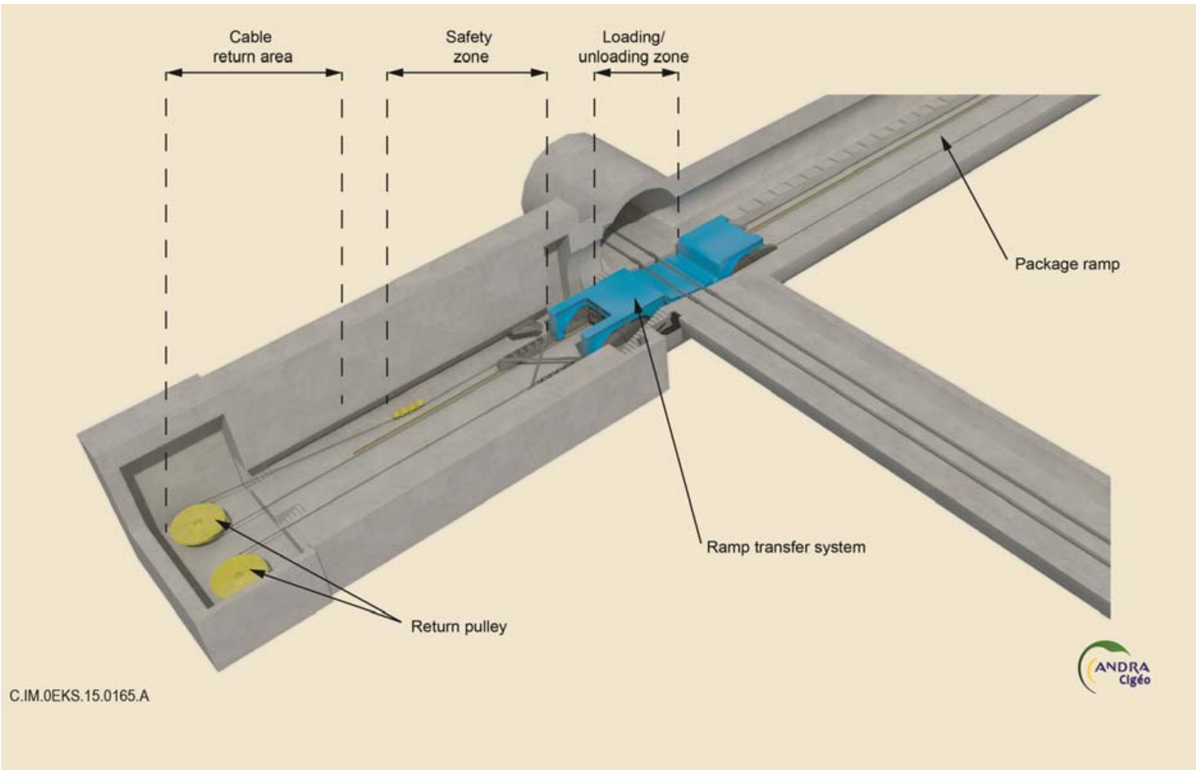

Figure 3.5-6 Lower station layout

3.5.3.5 The characteristics of the transfer vehicle

The characteristics of the vehicle, at this stage, meeting the operating conditions of 3.5.3.2 are as follows:

- height (without cask): 2.46 m;
- length: 22.78 m;
- width: 4.50 m;
- unladen weight: 80 t;
- maximum laden weight: 210 t.

The main vehicle equipment items are as follows:

- vehicle structure;
- the wheel rocker arms (running wheels and guide wheels);
- the emergency brake;
- the backup emergency brake;
- the anti-lift systems;
- the cask retaining system;
- the cable deflectors;
- the synchronisation pulleys;
- the batteries.

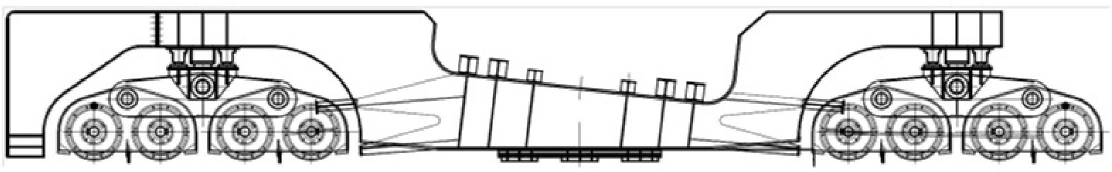

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Figure 3.5-7 Partial side view of the vehicle

<u>Vehicle structure and wheel rocker arms</u>

The vehicle consists of a painted welded metal frame, fitted with sixteen wheels of approximately 900 m diameter of two different types, spread over rocker arms mounted on suspension actuators:

- eight guided or guiding wheels on the first rail, to position the vehicle on the track;
- eight plane, or load bearing wheels on the second rail, taking-up any variations in track spacing.

Anti-uplift components preventing the derailment of the vehicle are also connected to the wheel rocker arms. An anti-derailing device is provided between each single rocker arm.

With the exception of the frame, all the components of the vehicle are made of galvanized steel.

<u>Vehicle brakes: Emergency brake and backup emergency brake</u>

The transfer vehicle is fitted with two types of brake which are activated if the drive unit brakes are unable to slow the vehicle sufficiently. These are as follows:

- jaw type emergency brakes. A set of eight callipers is shared between two brake carriages located at the downhill end of the vehicle;
- track friction emergency brakes These are directly attached to the vehicle frame, above the rails. The vehicle rests on four load-bearing hydraulic actuators, one at each corner of the vehicle, at the seatings.

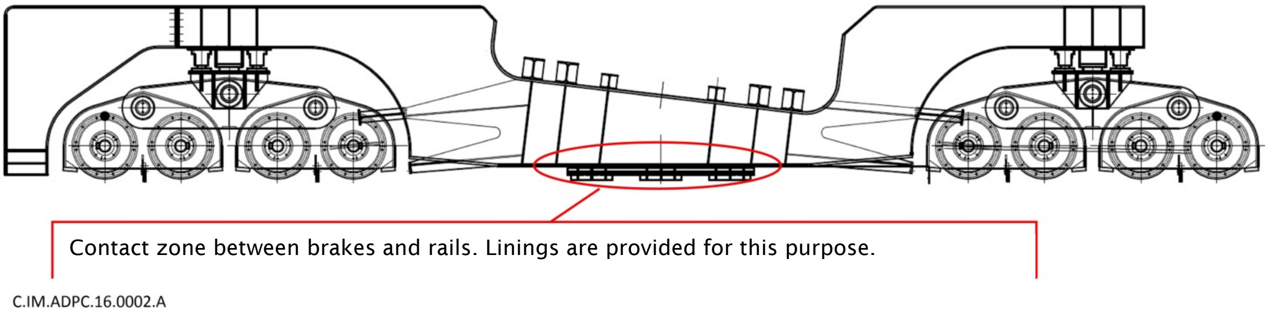

Figure 3.5-8 Location of backup emergency brakes on the vehicle

The braking systems are based on the principle of “positive safety brakes”. The brakes are automatically tripped when not supplied with hydraulic power. The vehicle's brakes and suspension actuators are fed by the hydraulic master control and distribution units located adjacent to the brake carriages. The hydraulic power is ensured by a motor and a manually controlled pump is provided in the event of a pump failure or loss of pressure in the hydraulic system.

<u>The cask support system,</u>

The vehicle platform is equipped with a quarter-turn locking system to secure the cask on the vehicle. Four locks are provided, one at each leg of the cask. This system is designed to withstand the effect of maximum vehicle deceleration, as well as the safe shutdown earthquake (SME).

<u>Synchronisation pulleys and cable deflectors</u>

The vehicle’s synchronisation pulleys form the link between the cable and the vehicle, but are not rotationally attached to the vehicle, and allow it to be driven in all situations.

<u>Batteries and electrical cabinets</u>

The vehicle's brakes and other electrical equipment are powered by a network of on-board batteries providing 12 hours’ autonomy contained in two cabinets at the top end of the vehicle. These ensure an independent power supply to the vehicle during descent and ascent.

These batteries are recharged in two ways:

- when parked in the station and in the maintenance area, by means of a multi-conductor rail system;
- during the transfer phases, by means of four alternators located under four different wheels of the vehicle, allowing additional, continuous battery charging. Each alternator is dedicated to one on-board electrical distribution line. A fifth (backup) alternator is place under a fifth different wheel.

The vehicle can also be powered when stopped by means of extension cables:

- within the maintenance area, to enable safe working close to the power rail;
- in the event that the vehicle becomes stuck inside the ramp tunnel for a period of more than 12 hours, a power cable can be used to manually connect the batteries to 230 Volt AC power sockets located at regular intervals along the length of the ramp (approximately every 100 m), in order to recharge them.

Close to the batteries are located electrical cabinets which manage the power supply to the vehicle’s electrical systems. These cabinets, as well as the batteries are as far away as possible from the cask.

3.5.3.6 The drive mechanism

The main components of the drive mechanism are as follows:

- the structure;
- the main winch;
- the drive pulleys;
- the deflection pulleys and rollers;
- the service brakes;
- the emergency brakes.

The components forming the drive unit are attached to welded frames which are in turn fastened to the civil engineering structure by means of anchors.

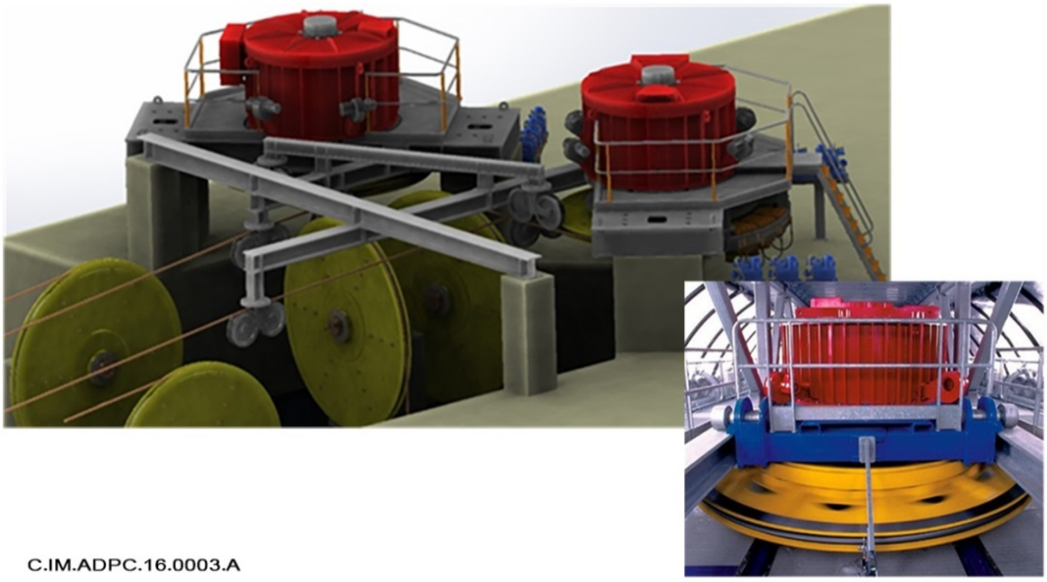

Figure 3.5-9 Drive mechanism layout

Because of the sheaved loop system, the vehicle is driven by two redundant drive pulleys. Each pulley is driven by a main winch comprising a direct drive motor (low speed motor without a step-down gearbox) the output shaft of which directly drives the drive pulley. The pulleys also have axle redundancy ensured by means of a redundant sleeve assembly. In the event that the outer sleeve is lost, the tension and the rotation are taken-up by the inner sleeve which is not directly in contact with the drive shaft.

The change of direction of the cable before it arrives at the drive pulleys is ensured by deflection pulleys preceded by deflection rollers.

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Figure 3.5-10 *Anti-derailing device*

Anti-derailing devices are also provided, in particular at pulley in-feeds and out-feeds to mechanically prevent the cable coming out of the pulley grooves. They are attached to the frame of the drive pulleys and the deflection pulleys.

Finally, the service brakes and emergency brakes are hydraulically-operated claw type brakes. Like the vehicle brakes, they are positive safety brakes. They are arranged around the two drive pulleys, with three claw service brakes and three claw emergency brakes, i.e. A total of twelve claw brakes (service and emergency). Each set of three brakes (service brakes or emergency brakes) is supplied by a hydraulic power unit, i.e. a total of four hydraulic power units.

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Figure 3.5-11 *Claw brake*

3.5.3.7 Electrical equipment in surface-to-bottom connections.

Power equipment / electrical equipment

The electrical equipment is located in dedicated rooms, some of which are located within the upper zone between the ramp head and the surface facilities.

These rooms comprise:

- two rooms housing the power equipment supplying the two machine rooms;
- two rooms containing the low-voltage main distribution boards (LVMD);
- two rooms containing the two power transformers;
- two rooms containing the electrical distribution, the information systems and the associated communication equipment;
- two rooms containing the data transmission equipment (Point to Point communication network: PP) and the “Process” systems (BAR-1, BAR-2 and BAR-3) using hard-wired data exchange. Each channel is housed in a dedicated room: room A1 and room B1;
- two rooms containing the data transmission equipment (High-Frequency radio communication network: RC) and the “Process” systems (BAR-1, BAR-2 and BAR-3) using safety programmed data exchange. Each channel is housed in a dedicated room: room A2 and room B2;
- the local control room (SCL) which centralises all data and commands relating to the “ramp transfer” system and from which the ramp transfer system can be remotely controlled in the event of unavailability of the centralised control room. The local control room is initially used for starting-up ramp transfer system tests.

The electrical rooms of the lower station comprise:

- two rooms containing the electrical distribution switchboards, the information systems and the associated communication equipment;
- two rooms containing the data transmission equipment (Point to Point communication network: PP) and the “Process” systems (BAR-1, BAR-2 and BAR-3) using hard-wired data exchange. Each channel is housed in a dedicated room: room A1 and room B1;
- two rooms containing the data transmission equipment (High-Frequency radio communication network: RC) and the “Process” systems (BAR-1, BAR-2 and BAR-3) using safety programmed data exchange. Each channel is in a dedicated room: room A2 and room B2,

It should be noted that the “ground level” power supply cabinets are located in fire sector rooms.

Process/Data and communication support matrix

The matrix presented below defines the support systems used by the Process, information and Communication systems, as well as the principles of redundancy.

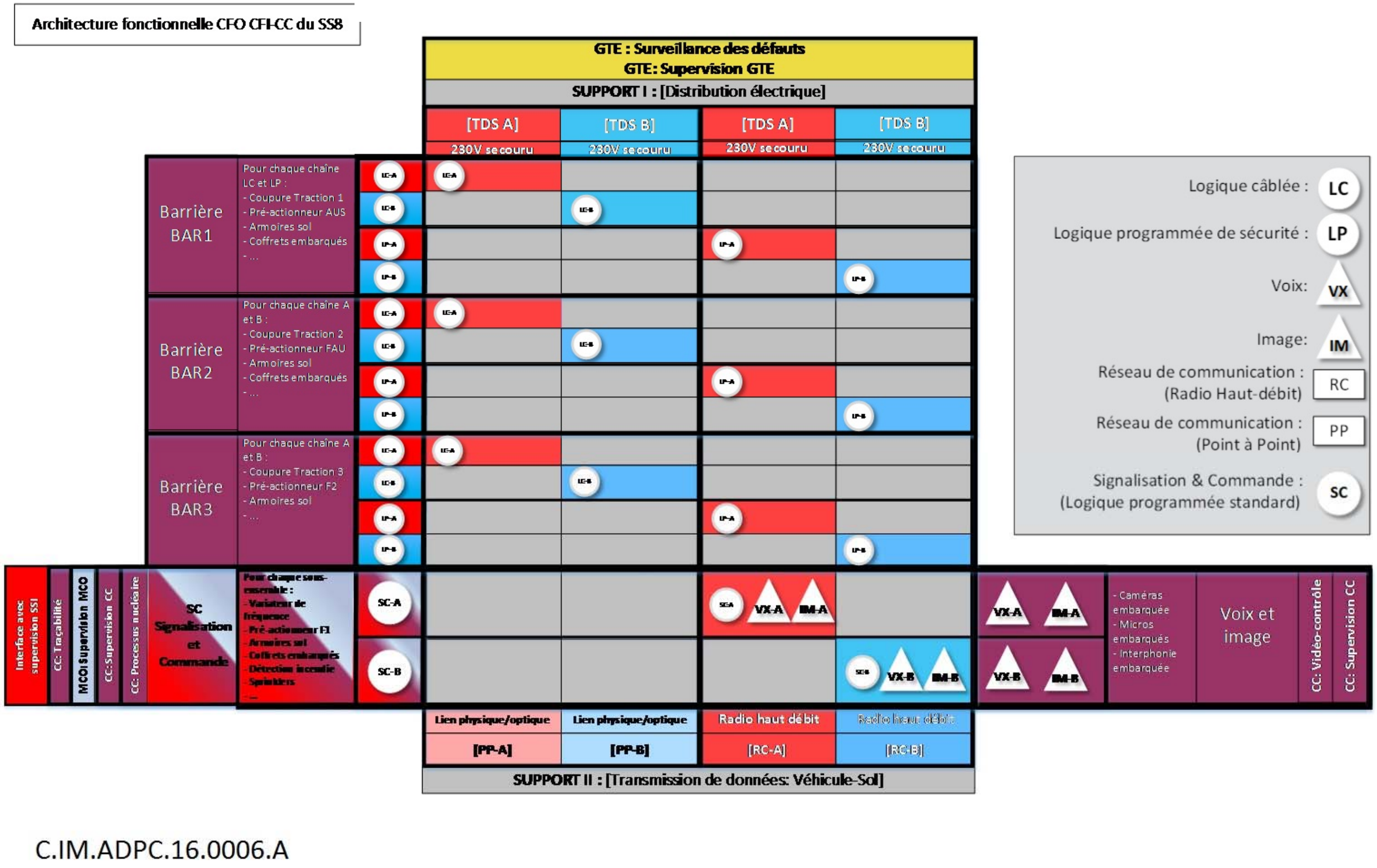


Figure 3.5-12 Process/Data and communication support matrix

Each Support System has a (low voltage) electrical distribution part [TDS] supplying power to the different process safety barriers [BAR] and a data transmission part [PP]/ [RC] transmitting data between the vehicle's on-board systems and the different control centres.

The Support System (including the two electrical distribution systems and the four data transmission systems) are mutually independent, regardless of their location (upper station, lower station, track, vehicle). This serves in particular to minimise common modes.

The power and control system supplies are separated, which explains why the machinery is not shown in this matrix.

<u>Machinery power supply</u>

The electrical distribution solution adopted uses two electrical power supplies of minimum 230 V each, which can power the low-speed motors, the frequency-variable drives and their auxiliary equipment.

The drive motors are supplied by separate sources. Each motor has its own dedicated power transformer. These transformers are emergency-supplied. However, the surface-to-bottom link does not have its own diesel generators.

Each power supply is designed to simultaneously power both low-speed motors, via a controlled link, in the event of the failure of the second power supply.

It should be noted that these supplies can return the braking energy produced by the motors to the power supply network. In the event that this power cannot be absorbed by the power network, braking resistors are provided in order to dissipate the energy.

<u>Upper and lower station power supply</u>

The upper and lower stations are each fed by two power supplies, one per distribution system [TDSA] and [TDSB]. No backup connection is provided between these two distribution systems.

<u>Track power supply</u>

The track power supplies must be able to supply the different relays of the data transmission systems and the vehicle power via extension cable connection points. These power supplies are not yet defined at this stage.

<u>Control room power supplies</u>

The cabinets associated with the surface-to-bottom connection are located in the central and the local control rooms. They require to be powered. These are not yet defined at this stage.

3.5.3.8 Instrumentation and control equipment

The whole of the "ramp transfer" system control and command architecture is broken down into three parts:

- the engineered safeguard systems (BAR) which oversee the data acquisition and processing system;
- the Instrumentation and control (CC) system which recovers the data supplied by each of the safeguard systems and delivers the information displayed on the Human-Machine Interface (HMI);
- The Human-Machine Interfaces (HMI) which, by means of screens, enable the operator to view information from the BAR and CC systems. The HMIs are located in the Centralised Control Room (dedicated centralised control station for ramp transfer system operations) and in the local control room (consoles situated at the head of the operating ramp). Inter-locks are established between these two potential control positions to prevent any risk of dual control.

- Human-Machine Interface

The options available to the operator differ according to the Human-Machine Interface station. The detection of an abnormal phenomenon triggers a signal on a HMI station. The allocation of signals to the different HMI stations is not yet defined at this stage of the project.

- Tension

The sheaved looped cable system adopted requires two tension pulleys to be provided (one on each side) in order to generate sufficient tension in the cable and ensure its adherence to the drive pulleys.

A 26.5 t metal counter-weight is hung from each pulley in order to tension the cable. It travels vertically within the tensioning pit over a distance of approximately 12 m:

- 5 m are allowed for the operating travel of the cable (elastic cable variation);
- 7 m are allowed to cater for the permanent elongation of the cable due to ageing.

Each counter-weight is guided by a vertically sliding guide system attached inside the pit.

- Station equipment

The sheaved looped cable system adopted requires two return pulleys to be provided in the lower station to return the cable to the either the upper station or the synchronisation pulley at the lower end of the vehicle. They are attached to the return structure which, like that of the upper station, is welded and fastened to the civil engineering structure.

Defection rollers fitted with cable anti-derailing devices are provided to guide the cable around the return pulleys.

Retractable track end buffers are provided in each station. These serve:

- to position the vehicle on the track for the cask loading/unloading phases;
- to cushion the arrival of the vehicle;
- to hold the vehicle in position during the loading/unloading phases,
- to enable the vehicle to move vertically relative to the track (during the loading/unloading phases);
- to enable the vehicle to pass into the upper station (to reach the maintenance area);
- to stop the vehicle in the event of accidental overspeeding when entering the station (up to 3 m/s) with a deceleration of less than 1 g. The sizing of the buffers is presented in the report.

Furthermore, in each station, the continuity between the platform and the vehicle for loading/unloading operations is ensured by a system of independent pivoting rails with a 45° end taper which swing up onto the vehicle once it is halted in the station. The tapered rails take up the vehicle's lateral play.

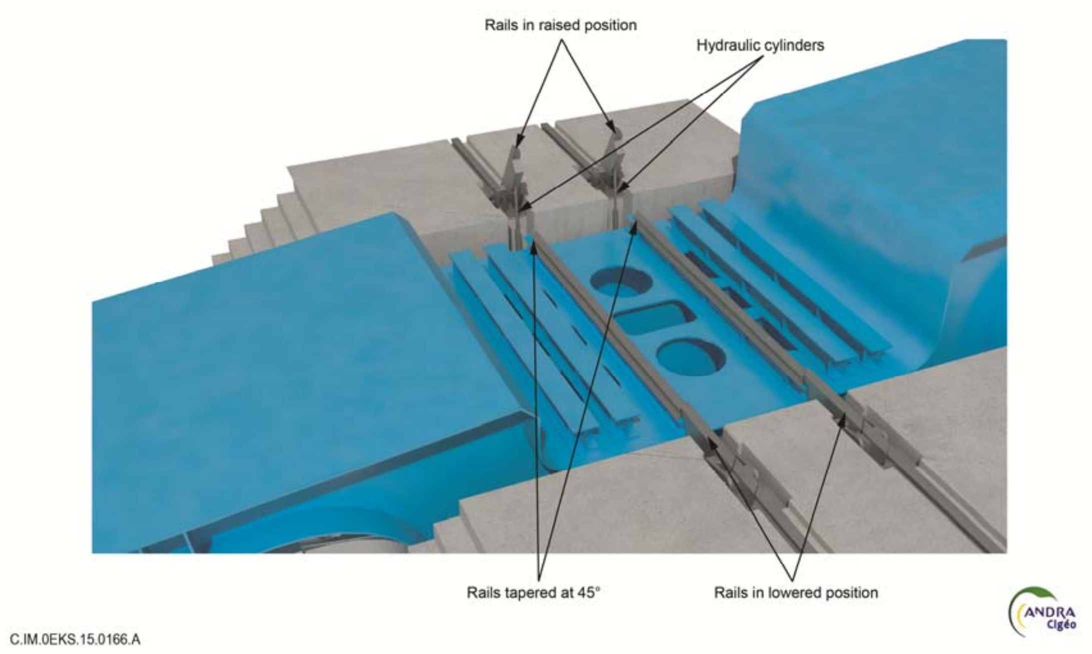


Figure 3.5-13 Platform/vehicle continuity system configuration

- **Support equipment**

The assembly vehicle used for installing the lower station cable return zone equipment is also used for the maintenance of that same zone. This maintenance vehicle is stored in the maintenance area, next to the track, when it is not in use. A modular hydraulic crane arm can be mounted on this vehicle for performing maintenance operations on the track and in the lower station. When used during maintenance phases, the maintenance vehicle is attached to the downhill end of the transfer vehicle. The tractive effort is then supported by the transfer vehicle.

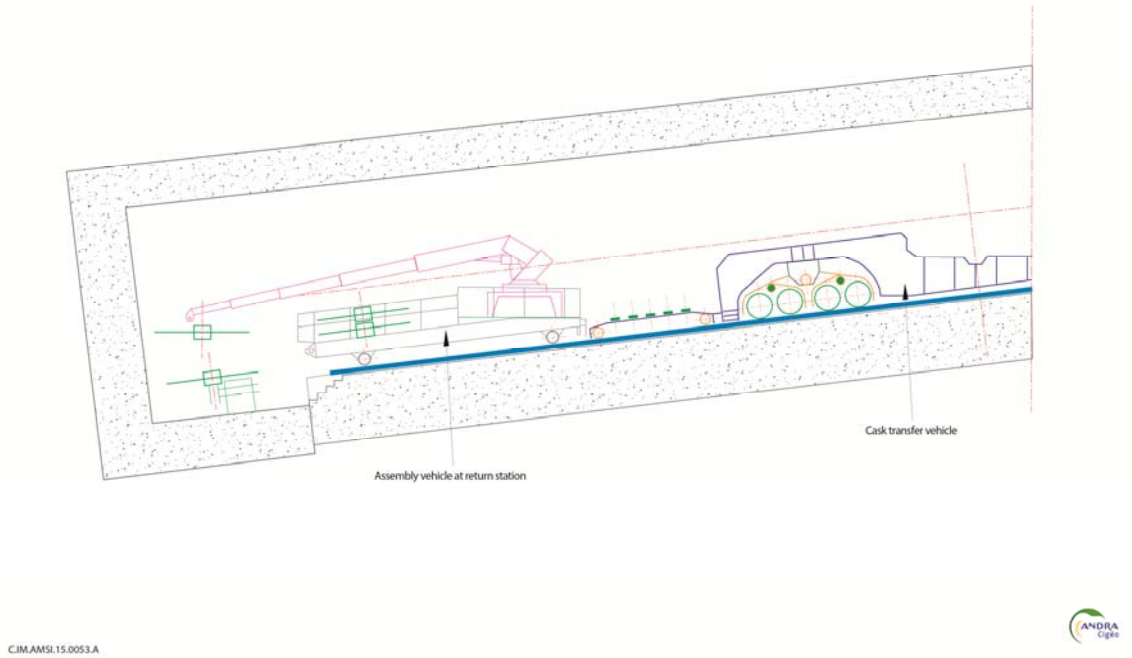


Figure 3.5-14 Maintenance vehicle in cable return zone

3.5.4 “Shaft zone” surface-to-bottom connections

The “shaft zone” contains shaft connections between the surface facility and the underground facility. The shafts independently serve the construction and the operating logistical support zones. Some shafts will serve for the transfer of personnel or equipment, while others serve only for ventilation. They are constructed during phase T1.

The “Shaft zone” comprises:

- Operating zone shafts (located in the operating logistical support zone):
  - ✓ 1 “operating” personnel transfer and fresh air supply shaft (VFE);
  - ✓ 1 operating zone exhaust air return shaft (VVE);
  - ✓ 3 optional shafts (HLW exhaust air extraction shaft (V-HA), sealing shaft (S) and waste package shaft (C).
- Construction zone shafts (located in the construction logistics support zone):
  - ✓ “construction” personnel transfer and fresh air supply shaft (VFT);
  - ✓ construction equipment and material delivery and removal shaft (MMT);
  - ✓ construction zone exhaust air return shaft (VVT).

The total height of the shafts varies from 510 to 550 m. The cross-section is circular with an effective diameter of the order of 6 to 8 m according to the shaft (at end of basic engineering design). The structures are sized on the basis of the through-flows during the period of operation and closure of the repository.

A ventilation scheme, including the operation of the shafts is presented in chapter 3.5.13.2.

After passing through the first metres of weathered ground, the shafts are excavated using conventional blasting techniques. The option of using alternative excavation methods is nevertheless being studied. Conventional excavation consists in digging a dead-end shaft by excavating below a single- or multi-level deck working stage suspended by cables from a headframe at the surface. This deck is moved by means of a system of winches and cables, which is also used for moving all the equipment installed in the shaft (excavation buckets, personnel lift, lighting, etc.). These principles have already been applied to sink the shafts of the Centre Meuse Haute-Marne Underground Research Laboratory.

In the overlying layers, the liner is made of concrete. Within the Callovo-Oxfordian layer the liner is concrete, but a compressible[48] material may be placed between the liner and the ground.

The shafts are designed as sealed shafts in the Barrois aquifer. Within the other overlying formations (Kimmeridgian and Oxfordian limestones) a liner is used to withstand the hydrostatic pressure. A seal is formed at the base of the Oxfordian limestone (the top of the clay rock), Any ingress of water is collected.

The figure below shows the shafts providing access to construction and operating logistics zones. The two zones are physically separated at the bottom.

[48] This compressible material would enable the liner to be installed directly, while allowing a reduction of thickness of the (rigid) concrete liner and shortening the operational waiting time between the support and lining operations.

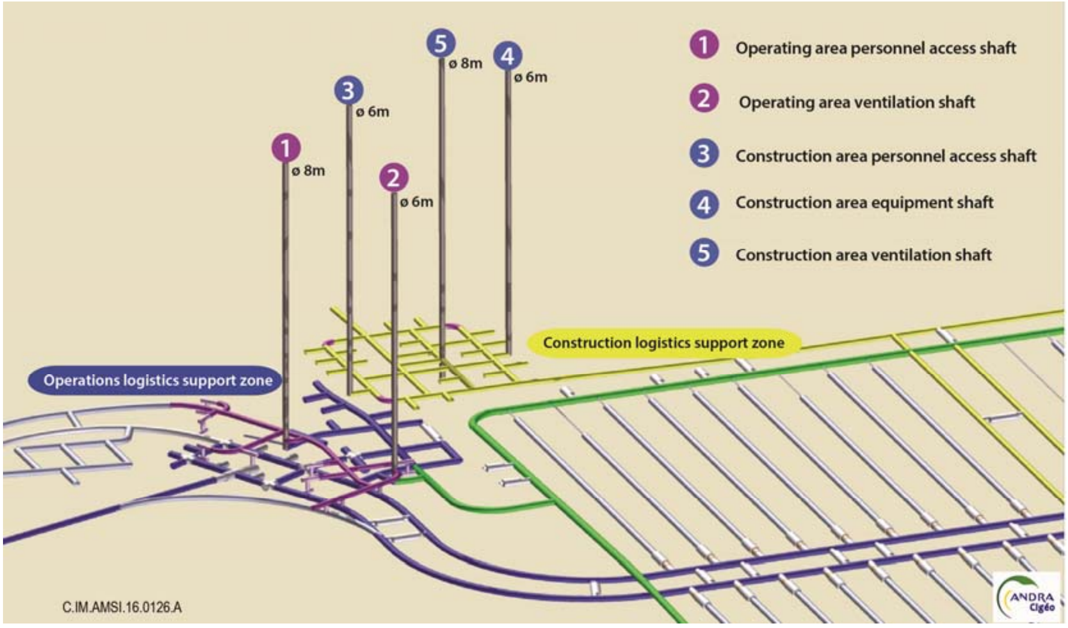


Figure 3.5-15 Shafts within the logistical support zones (view at end of the basic engineering design stage)

3.5.5 Shaft functions and equipment (at end of the basic engineering design stage)

3.5.5.1 Operating fresh air ventilation shaft (VFE)

The operating fresh air ventilation shaft (VFE) serves exclusively for operation and is used:

- to transfer personnel from the conventional surface facilities to the Logistical Support Zone (ZSL);
- to ventilate and supply fresh air to the underground structures from ventilation units located at the surface.

At the surface, the operating fresh air ventilation shaft is located within the Operating Zone, and underground within the Operating Logistical Support Zone.

- air locks are installed inside the shafts to seal the surface buildings and limit leakage;
- a 20-person capacity main cage (car) is installed, together with an 8-person emergency cage in the event of an incident;
- a lift machine room is located inside a building situated at ground level without an exposed tower (headframe system);
- the shaft is associated with a surface building suitable for housing the operating personnel, integrating a ventilation plant (5 ventilation units) and for installing technical rooms.

3.5.5.2 Operating exhaust air extraction shaft (VVE)

The Operating exhaust air extraction shaft (VVE) serves exclusively to return operating zone exhaust air by combining the air flows from the “clean” underground ambient ventilation system (class C1) and the ILW-LL disposal cells and handling areas (class C2) which are filtered before discharge. The shaft is connected to the surface level ventilation units.

At the surface, the operating exhaust air extraction shaft is located within the Operating Zone, and underground within the Operating Logistical Support Zone.

3.5.5.3 Construction fresh air ventilation shaft (VFT)

The construction fresh air ventilation shaft (VFE) serves exclusively for the underground facility construction activities and is used

- to transfer personnel from the conventional surface facilities to the Construction Logistical Support Zone;
- to ventilate and supply fresh air to the underground structures under construction from ventilation units located at the surface.

At the surface, the construction fresh air ventilation shaft is located within the Construction Shaft access zone, and underground within the Construction Logistical Support Zone.

- a 50-person capacity main cage (car) is installed, together with an 8-person emergency cage in the event of an incident;
- a lift machine room is located inside a building situated at ground level without an exposed tower;
- the shaft is associated with a surface building suitable for housing the construction personnel, for integrating the 4 ventilation units and for installing technical rooms.

3.5.5.4 Construction exhaust air return ventilation shaft (VVT)

The Construction exhaust air ventilation shaft serves exclusively to extract stale air from the drifts under construction. The shaft is connected to the surface level ventilation units.

At the surface, the construction stale air ventilation shaft is located within the Construction Shaft access zone, and underground within the Construction Logistical Support Zone.

- the shaft contains no hoisting equipment, but inspections are carried out using a self-propelled crane with access platforms;
- the shaft is associated with a dedicated surface building housing the ventilation system (4 ventilation units).

3.5.5.5 Construction equipment and materials shaft (MMT)

The construction equipment and materials shaft (MMT) is essentially a dedicated construction activity shaft which serves:

- to transfer equipment and materials for construction, as well as bulky nuclear process equipment;
- to carry muck from the excavations to the surface.

At the surface, the construction equipment and materials shaft (MMT) is located within the Construction Shaft access zone, and underground within the Construction Logistical Support Zone.

- The incoming equipment and materials are transferred in a cage necessary for transferring heavy loads such as concrete mixer trucks, plant equipment and handling equipment. The cage has a load capacity of 30 tonnes;
- The construction debris flows are removed via the construction equipment and materials shaft via an extraction skip with an estimated capacity of 2850 m^3 per day. The effective load of the skip is close to that of the cage (approximately 30 tonnes);
- an 8-person capacity emergency cage is installed in the event of an incident. It can also be used for shaft maintenance operations;
- skip handling and cab lifting machinery is installed in a building with a steel tower;
- A surface building associating the headframe (60 m high) and a technical building is linked to the shaft.

3.5.6 Underground facility logistical support zones

Two separate logistical support zones provide logistical support to the construction works and to the operation of the repository. The structures are sized to meet the through-flows over the period of operation and closure of the repository. These structures are for the most part constructed during the initial works phase. Nevertheless, developments associated with feedback/improvement and optimisations can be envisaged during the different phases of the life of the repository.

The drifts are excavated using the conventional method (road header machine). The stability of the drifts during the 150 year operating period is ensured by flexible support. As they are not used for process circulation, their internal dimension does not require to be strictly maintained.

3.5.6.1 The construction logistics support zone

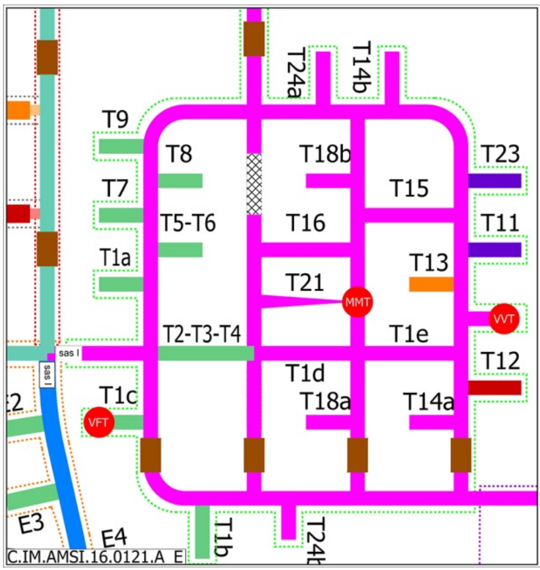
This zone enables the passage of incoming flows for the construction of the works: materials, equipment, plant and networks (electrical and ventilation), as well as outgoing materials flows (muck) and the flows associated with the rooms and with emergency response and assistance provisions. It includes the construction shafts which are connected via the logistic support zone to the ILW-LL and HLW disposal construction works.

The rooms of the logistical support zone perform the following functions:

- vehicle/equipment storage;
- maintenance;
- electrical; communications and security systems (CFI), high and low voltage power supply (CFO), HV/LV;
- living and emergency areas.

The drifts are excavated using the conventional method (road header machine). The stability of the drifts during the 150 year operating period is ensured by flexible support. As they are not used for process circulation, their internal dimension does not require to be strictly maintained. The drift cross-sections are sized to suit the dimensions of the flows. The sizing leads to structures with an effective internal diameter of approximately ten metres. Intersections can be slightly larger in size.

The ventilation of the construction logistical support zone is ensured by air supplied via the construction fresh air ventilation shaft (air inlet and personnel transfer shaft) (see 3.5.13.2). The logistics support zone delivers fresh air to the upper part of the construction drifts to the disposal section construction works. Full section air return drifts to the construction stale air ventilation shaft (construction return air shaft in the logistical support zone).



Spaces within the CONSTRUCTION logistics support zone (ZSL)	
T1a/T1b	Personnel/Construction vehicle parking area
T1c	Visitor's vehicle parking area
T1d/T1e	Site vehicle parking drift
T2	Excavation equipment storage area
T3	Fire vehicle storage area
T4	Firemen's vehicle storage area
T5	Emergency station
T6	Emergency services recess
T7	Office area
T8	Canteen area
T9	Toilet area
T11	Air/Gas storage area
T12	HV/BV CFO room
T13	CFI room
T14a/T14b	Small equipment maintenance room
T15	Large equipment maintenance room
T16	Construction waste room
T18a/T18b	Roof support buffer storage
VFT	Personnel/construction/emergency fresh air ventilation shaft
MMT	Construction equipment/materials shaft
VVT	Construction stale air ventilation shaft
T21	construction equipment and materials (MMT) shaft access opening
T23	Fuel room
T24a/T24b	Washing area

Figure 3.5-16 Plan view of the construction logistical support zone (illustration at end of basic engineering design)

3.5.6.2 The operating logistics support zone

This zone enables the passage of incoming operating flows to the disposal cells during operating, maintenance, renovation and closure phases: waste packages, equipment, plant and networks (electrical and ventilation), as well as material flows during the maintenance and closure phases and the flows associated with the rooms and with emergency response and assistance provisions. It comprises the operating shafts and ramps which are connected via this zone to the ILW-LL and HLW disposal operating zones.

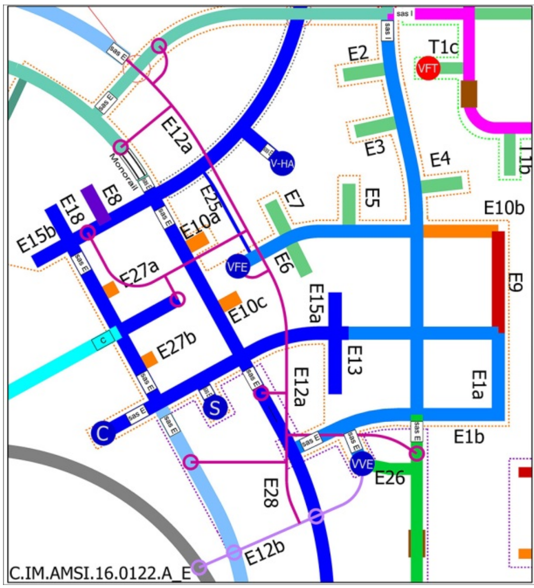
The rooms of the logistical support zone perform the following functions:

- process circulation;
- vehicle/equipment storage;
- maintenance;
- electrical; communications and security systems (CFI), high and low voltage power supply (CFO), HV/LV;
- ventilation: a plenum, located above the drifts of the operating zone, which is connected to the operating fresh air shaft supplies ventilation air to drifts of the various disposal sections. It supplies air to 9 feeders (see:3.5.13.2: Ventilation):
  - ✓ North ILW-LL connection drift air supply;
  - ✓ South ILW-LL connection drift air supply;
  - ✓ North and South ILW-LL air return drift air supply;
  - ✓ air return drift protected path air supply;
  - ✓ operating logistical support zone air supply;
  - ✓ package transfer ramp and lower station air supply;
  - ✓ service ramp and reference structure air supply;
  - ✓ HLW disposal section evacuation/emergency drift air supply;
  - ✓ HLW operating connecting and access drift air supply.

It should be noted that stale air from the underground facility converges towards the operating exhaust air extraction shaft (VVE) to be discharged at the surface. The stale air is transferred towards the operating exhaust air extraction shaft by means of an exhaust network installed in the dome of the drifts. In the case of the ILW-LL disposal section, the different air removal networks are directly connected to the operating exhaust air extraction shaft by the exhaust plenum.

The drifts of the operating logistical support zone are excavated using conventional methods, with exception of the connecting drift extending from the service ramp, for which a tunnel boring machine is used.

The drift sections are sized to suit the dimensions of the flows. The sizing leads to structures with an effective internal diameter of approximately ten metres. Intersections may be slightly larger.



Spaces within the OPERATING logistics support zone (ZSL)	
E1a	Personnel and visitor's vehicle parking area
E1b	Maintenance vehicle room GRA
E2	Personnel evacuation vehicle area
E3	Fire extinguishing vehicle area
E4	Firemen's vehicle area
E5	Radiation monitoring emergency station
E6	Emergency services recess
E7	Accommodation area
E8	Liquid effluent room
E9	LV CFO room
E10a	CFI room SS1
E10b/E10c	CFI room SS4
E12a	Ventilation - Air supply plenum
E12b	Ventilation - Air extraction plenum
E13	Process support room
E15a/E15b	SS1 equipment storage room
E18	Cask buffer storage room
VFE	Personnel / fresh air ventilation shaft
VVE	Stale air ventilation shaft
V-HA	HLW stale air ventilation shaft (optional)
S	Shaft / Sealing shaft access (optional for 2040)
C	Shaft / HLW package shaft access (reserve for 2075)
E25	Service gallery (Cables)
E26	Ventilation equipment room
E27a/E27b	SS8 electrical room
E28	Chilled water production room

Figure 3.5-17 Top view of the operating logistical support zone (illustration at end of basic engineering design)

3.5.7 Transfer from the operating logistical support zone to the HLW and ILW-LL disposal cells

3.5.7.1 Underground transfer cart

Once the ramp transfer vehicle arrives in the lower station, the cask containing a disposal package is picked up by a transfer cart (bottom cart). This transfer cart transfers the casks from the transfer ramp lower station to the entrance of the ILW-LL and HLW access drifts.

This cart travels within the connecting drifts and sets down the casks at the entrance to the access drifts of the ILW-LL disposal cells (see 3.5.8). These carts are of a different design to that of the shuttles. Because of the longer distances they are required to cover, their electrical cabinets are placed vertically on the cart to reduce their longitudinal dimension, in particular for travelling through bends and over turntables. The cart is powered by electric rails in the invert.

Figure 3.5-18 Bottom transfer cart

The underground transfer cart mainly comprises:

- a box-section support frame;
- two travel bogies, each equipped with four rollers and drive motors to ensure their movement;
- a positive safety rail clamp braking system with seismic qualified anti-lift/derailing systems;
- a hoisting system and its hydraulic power unit for lifting the cask vertically (Z direction) and for positioning it in the horizontal (XY) plane;
- electrical and control cabinets grouped together at the rear of the frame;
- a set of sensors and instruments for monitoring and controlling the different movements and operating parameters of the cart.

Two carts may be in circulation to achieve the required disposal rates. A third, backup cart is standing by in the maintenance area.

The full casks are unloaded from one side of the ramp transfer vehicle by a first cart which transfers its full cask while the second cart sets down an empty cask on the vehicle before it returns up the ramp. This second cart then awaits the full cask of the next cycle.

<u>Principles of cart design</u>

- ***Anti-lift - Anti-derailing systems***

In order to prevent any risk of derailment, the bottom transfer cart is fitted with four anti-lift systems. They are mounted directly under the bogie end carriages and located between the rollers.

- The double cheeks on the rollers guide the cart on the rails. The redundancy of the cheeks helps secure this function in the event of the failure of one cheek,
- The anti-lift devices can perform the anti-derailing function, e.g. in the event of a broken roller,
- Braking.

On account of the high level of reliability required, the cart braking system is based on an architecture with three separate and complementary levels of braking:

- Electric braking: this braking system is mainly used during the slowing and stopping phases or when the card is moving on a downhill slope. In these configurations, the four motors act as generators and feed the recovered energy back to the power supply network via the frequency-variable drives,
- Service braking: this function is ensured by power-off disc brakes incorporated within the motors. They are used during position holding phases for cart ARH1 and upon detection of faults in the type ARH2 stopping sequences;
- Safety braking: in the event of an emergency stop, overspeeding or detection of an obstacle, for example, the ARH3 type safety brake is activated. Braking is achieved by means of two rail-clamp brakes mounted directly on the rear bogie structure. These brakes are also used to hold the cart in the stopped position (on a turntable, beneath a cask, etc.);

- ***Cask protection shock absorbers***

Insofar as the bottom transfer cart is not under-travelling, measures are taken to limit the consequences of possible impact of an empty cart against a cask in the event of a failure or an earthquake for example. Two shock absorbing bumpers are mounted between the technical unit and the cask for this purpose.

The characteristics of these shock absorbers are as follows:

- presence of hydraulic shock absorbers;
- total energy dissipation capacity: 2 x 55 kN.m (for maximum kinetic energy of 2 x 45 kN.m);
- maximum impact velocity: 10 km/h (high speed mode);
- hydraulic fluid: HFC fire-resistant (water-glycol).

3.5.7.2 Running tracks

The transfer cart running tracks are formed of continuous rails within their standard sections, with interruptions of only a few centimetres at discontinuities (turntables, ventilation air locks and ramp transfer). The electrical power is supplied via multi-conductor rails located between the running rails.

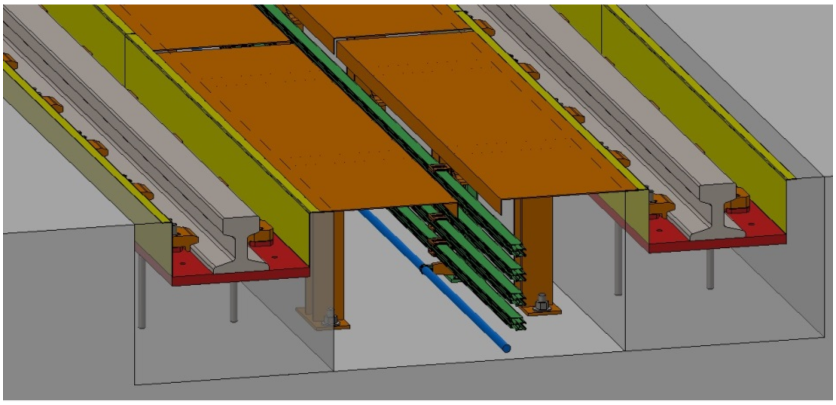


Figure 3.5-19 illustration of running track

3.5.7.3 Turntables around the ramp transfer system lower station

Five turntables are provided around the lower station for orienting the (non-under-travelling) transfer cart. These tables are similar to the ramp zone turntable at the surface. These enable the carts to be turned trough +/-90°. They enable the carts to gain access to:

- the two ILW-LL connecting drifts;
- the HLW connecting drift;
- the logistical support zone maintenance area;
- to both side of the ramp transfer system lower station.

3.5.7.4 Logistical support zone turntable and rail turntables

The casks are set down by the carts and picked-up by the ILW-LL or HWL shuttles at the intersections between connecting drifts and access drifts. Rail turntables are installed at these positions to enable the passage of either the underground cart or the shuttles. These turntables orient the (electric and running) rails in the desired direction and replace rail crossings.

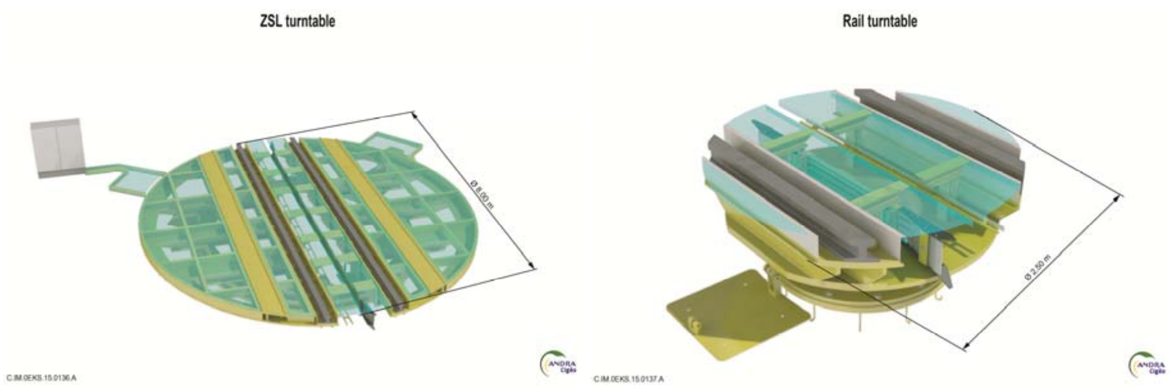


Figure 3.5-20 Turntables in the underground facility

3.5.8 ILW-LL repository zone

The ILW-LL zone is connected to the construction and operating logistical support zones by construction and operating connecting drifts and an air return drift. It consists of a single disposal section

3.5.8.1 Main design requirements for the ILW-LL cells

The design of the ILW-LL cells complies with the safety functions and requirements associated with the post-closure safety objectives presented in the DOS-AF.

The design requirements are as follows:

- optimise the geometric shape of the ILW-LL cells to minimise the ratio of the excavated volume to the volume of disposed packages and limit the volume of concrete used;
- ensure the mechanical stability of the ILW-LL cells by means of a liner. This must be ensured over the period of reversibility;
- take account of the stresses that apply during the retrievability period (see DOREC) for the mechanical design of the ILW-LL drifts and cells;
- design horizontal ILW-LL package disposal cells (a maximum slope of 1% is tolerated for the nuclear process). The acceptable tolerance of +/- 1%, to take account of construction allowances and movement/deformation over time;
- orient the cells according to the direction of the main stress of the Callovo-Oxfordian formation;
- limit the use of steel for components remaining in place in the cells after closure, if it provides no substantial advantage with respect to operational safety, post-closure safety, reversibility or project costs;
- construct reference ILW-LL sells representative of the other cells of the same type: the number of reference cells will depend on the number of different cell types planned for in the first phase;
- limit the maximum excavated section to 65 m² (with a tolerance) for the cells put into operation in phase T1. This will be revised following the studies justifying the design of cells of larger dimensions, in particular with the construction of a large-scale demonstration cell (scheduled for the industrial pilot phase);
- the ILW-LL cells will be spaced apart at a distance equivalent to 5 diameters (outside distance between two cells) to limit mechanical disturbance (at the end of the basic engineering design stage). Studies will be conducted with a view to reducing this distance at the detailed engineering design stage, bearing in mind that the minimum distance for limiting physical-chemical interaction of cells containing complexing agents and salts on other cells is 30 metres;
- the waste disposal cells will be designed so that the air temperature remains below 50°C at all times;
- avoid the use of hollow bolts (e.g. “Swellex” or “split-set” type) if the use of radial bolts is required during the construction of the sections of drifts intended to receive seals and cells.

The main elements taken into account for designing the ILW-LL cell are:

- the environment of the geological medium:
  - ✓ the mechanical loading on the cell;
  - ✓ hydrological exchanges between the clay rock and the cell;
  - ✓ Seismic hazard.
- the conditions of ventilation (before closure) or lack of ventilation (after closure) and their impact on the processes that are involved:
  - ✓ thermal processes: thermal cycles transferred by ventilation (potentially coupled with heat released from waste);
  - ✓ hydrological processes: hydrological cycles transferred via ventilation, desaturation/resaturation of man-made and natural components;
  - ✓ Chemical processes: renewal or consumption of oxygen (redox state) and CO_2 (atmospheric carbonation).
- characteristics of waste packages and cell components:
  - ✓ temperature;
  - ✓ release of gas (hydrogen) according to type of waste;
  - ✓ Hygroscopic behaviour of some waste (such as saline waste).

3.5.8.2 ILW-LL architecture

The ILW-LL disposal section is organised around a framework of connecting and air return drifts, from which the ILW-L cells will be gradually constructed: access drift, hot cell and air duct. This framework of the section will be at least partially completed prior to the construction and operation of the section's first disposal cells.

The ILW-LL disposal section is deployed using the “advancing” method. In other words, the disposal cells are constructed then operated while moving away from the Operating logistical support zone. An operating plan of the ventilation is presented in section 3.5.13.2. The gradual deployment of the repository takes account of the construction of an initial repository phase (T1) followed by later phases. The duration of the development of the ILW-LL zone, extending over a period of approximately 60 years, leads us to consider the possibility of improvements and optimisations. . The representation of the disposal section layout on completion is therefore liable to change.

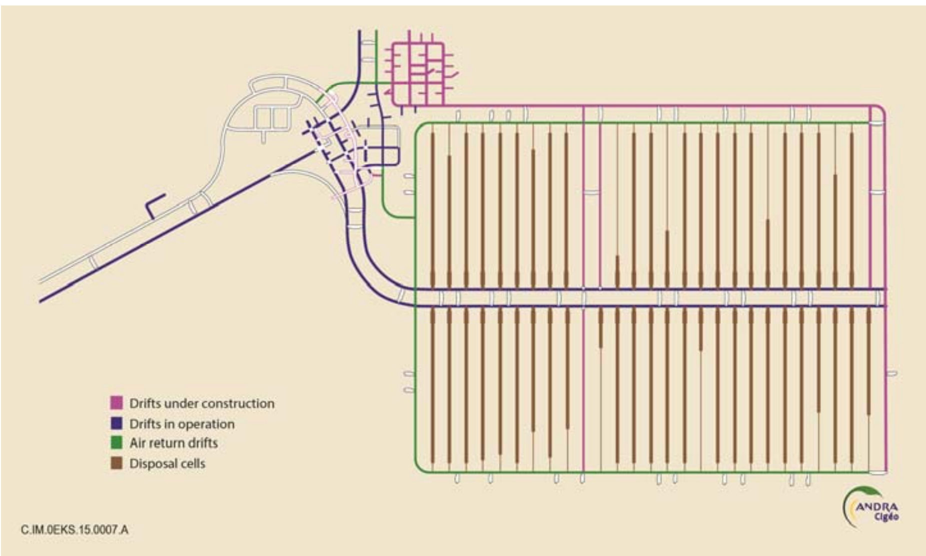


Figure 3.5-21 ILW-LL zone at completion

3.5.8.3 Architecture of the ILW-LL disposal section for phase 1

The architecture of the first phase constructed towards 2030 will serve as a support for the presentation of each of the underground structures, their functions and the transfer equipment. The data are those of the design at the end of the basic engineering design stage.

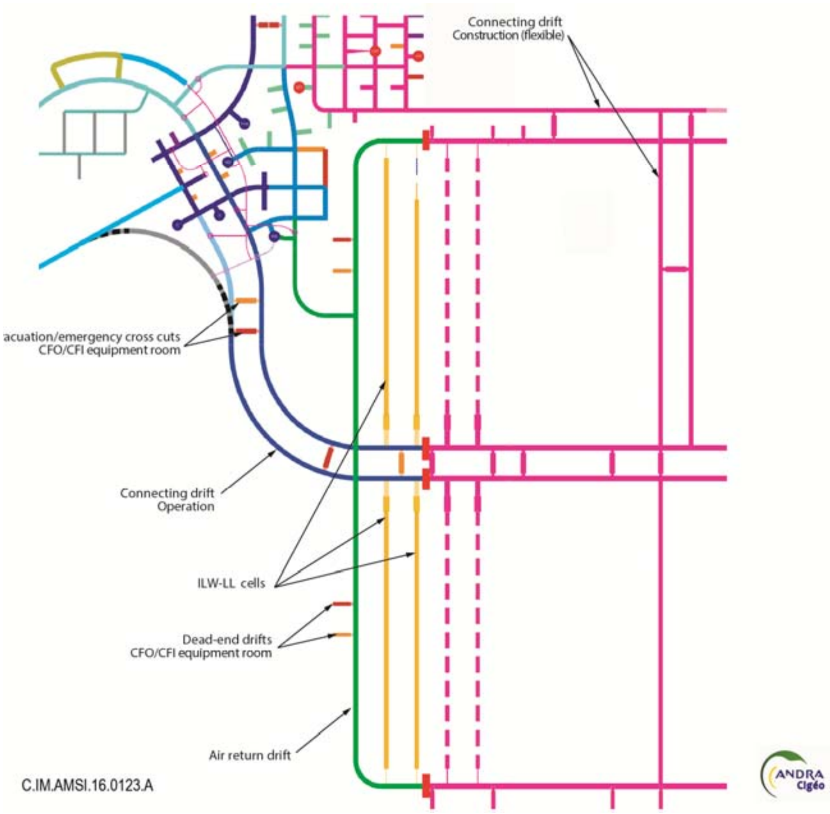


Figure 3.5-22 Top view of the ILW-LL disposal section for phase 1

3.5.8.4 Operation connecting drifts

The operation connecting drifts are connected to the access drifts of each disposal cell from the bottom of the ramps, passing through the logistical support zones.

The ventilation of each ILW-LL connecting drift (North and South) is in full section. The air is carried from the beginning of each connecting drift from the plenum via its own air supply feeder. The air is then removed at the end of each connecting drift then conveyed towards the operating exhaust air extraction shaft (VVE). The excavated diameter is of the order of 10 m,

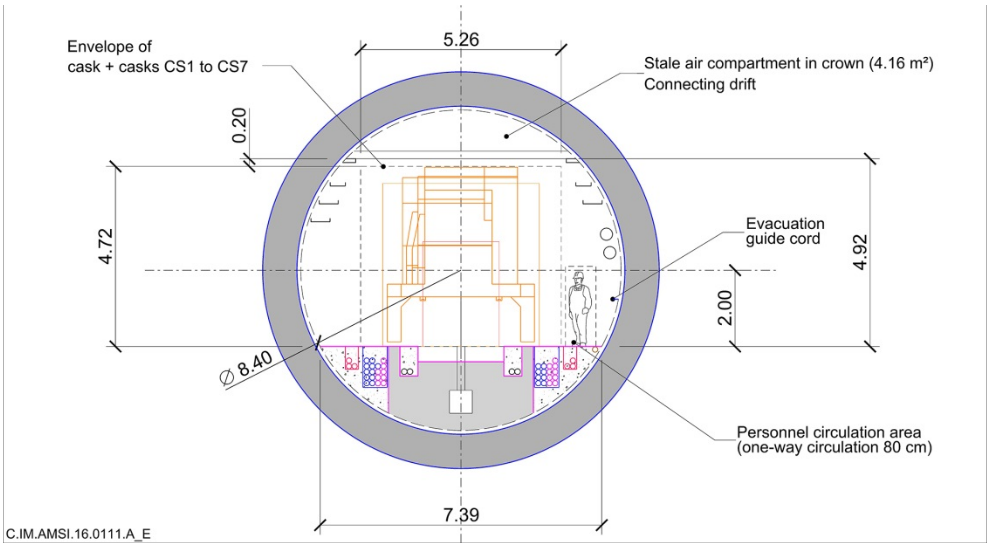


Figure 3.5-23 Operation connecting drift (standard section excavated by a tunnel boring machine, end of basic engineering design)

The effective diameter takes account of the following sizing elements:

- in the main section:
  - ✓ passage of the cask on the cart;
  - ✓ functional clearance defined by the process with also takes account of the vertical displacements linked to the kinematics of the cask, as well as the construction tolerances and the long-term movements of the infrastructure;
  - ✓ passage of operating personnel (one-way circulation);
  - ✓ Integration of a series of items of equipment, in particular:
    - an automatic fire detection and extinguishing system;
    - measuring sensors (air quality and velocity in full section) and a radiological monitoring sensor (radiation);
    - a heat exchanger for removing heat from the CFO/CFI cross cuts and a CFI cable tray;
    - a monitoring camera, a wifi network.
- in the invert:
  - ✓ rail and process power supply: the cart power is supplied in the centre of the invert between the running rails. emergency vehicles can circulate within this zone;
  - ✓ the access load transfers and rails in the access drift: the load transfers create an inaccessible zone for the passage of electrical networks and the installation of draw-in boxes. The upper limit of the positioning of the networks is also dictated by the crossings between the connecting drift and the access drift at rail level;
  - ✓ the integration of the electrical networks (HV, LV, CFI, etc.): the invert incorporates the electrical networks of the cells served by the connecting drift as well as the equipment powered by the second connecting drift (total separation of redundant networks);
  - ✓ effluent: liquid effluent collection channels are provided on either side of the drift. Fire and cooling networks are also provided in the invert.
- in the dome:
  - ✓ ventilation compartment: enables extraction of stale air, in particular in abnormal situations;
  - ✓ separating slab: separates the ventilation compartment from the standard section.

3.5.8.5 Construction connecting drifts

The construction connecting drifts enable work to continue in the section in operation. They provide access to the face of the disposal cells from the construction logistics support zone. The drifts are sized to enable the passage of construction machinery as well as equipment and construction flows.

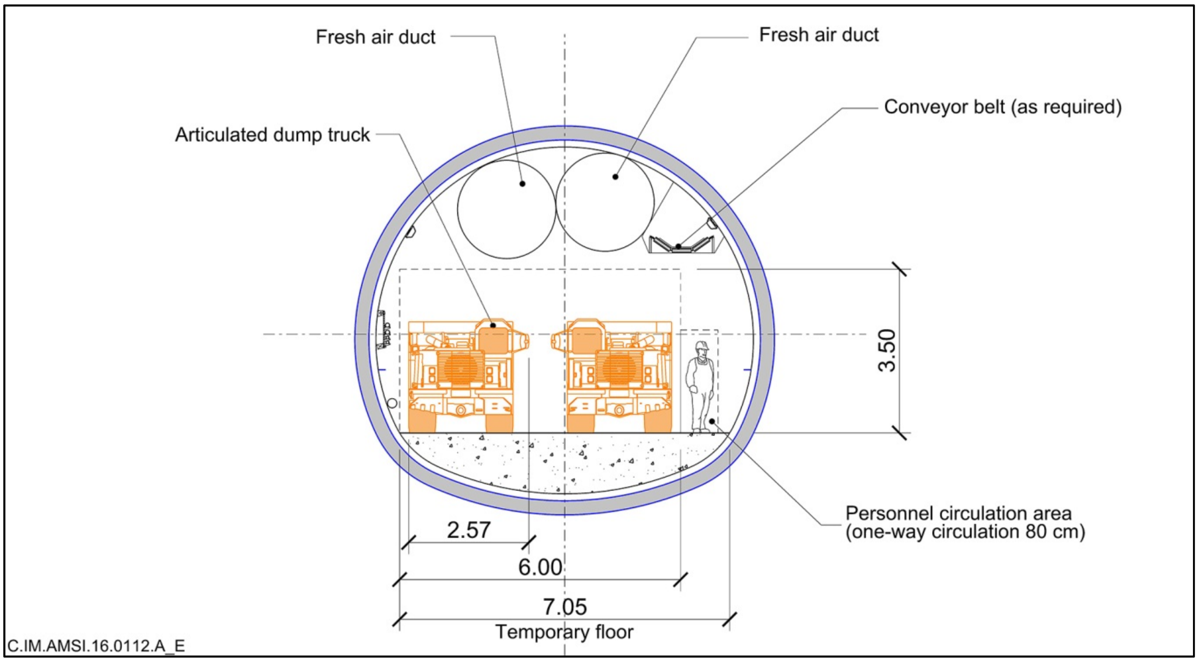


Figure 3.5-24 Construction connecting drift (standard section, end of basic engineering design)

Unlike the other drifts of the ILW-LL disposal section, they are of a “flexible” design and do not need to be strictly held in place but can be secured by the internal jig.

The section of the drift is similar to that of the construction logistics support zone drifts.

The flexible design of the construction connecting drifts leads to T, X or L-intersections with other flexible/rigid drifts.

3.5.8.6 Operation air return drift

The ventilation of each air return drift (North and South) is full section. The air is carried to the beginning of each air return drift from the air plenum by means of an air supply feeder specific to each drift. The air is then removed at the end of each drift then conveyed towards the operating exhaust air extraction shaft (). The protected path is ventilated by means of distribution feeder distributing air uniformly throughout the length associated with the path. The air is then directed towards the air return drift then taken-up by the air return air drift exhaust network.

This drift is constructed in a conventional way using a road header machine.

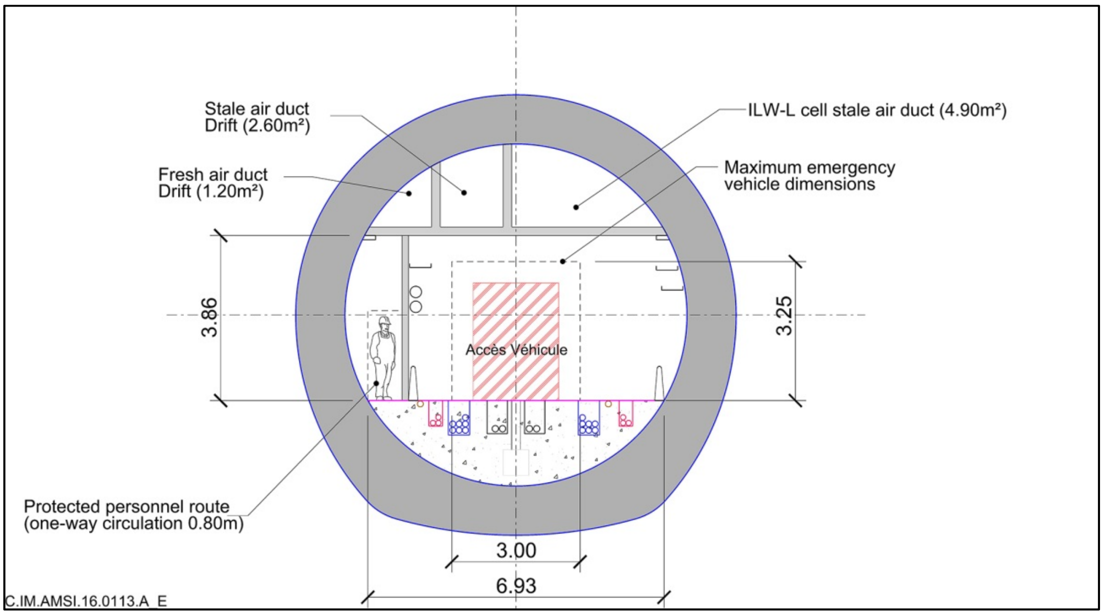


Figure 3.5-25 Operation air return drift (standard section excavated with road header machine at end of basic engineering design stage)

3.5.8.7 ILW-LL cell

ILW-LL disposal cells:

- are tunnels oriented according to the direction of the principal major stress,
- are connected at one end to an access drift, which allows air into the cell and at the other end to an air return drift for the air to exit, with a dedicated filtration room for each cell.
  - ✓ the HEPA filtration system and flow control damper of each cell are located in the air return drift,
  - ✓ a hot cell is located between the access drift and the usable part of the disposal cell,
  - ✓ the maximum usable part of the disposal cell is approximately 500 m. This length is compatible with the preservation of the undisturbed thickness of clay rock necessary for the justification of post-closure safety.

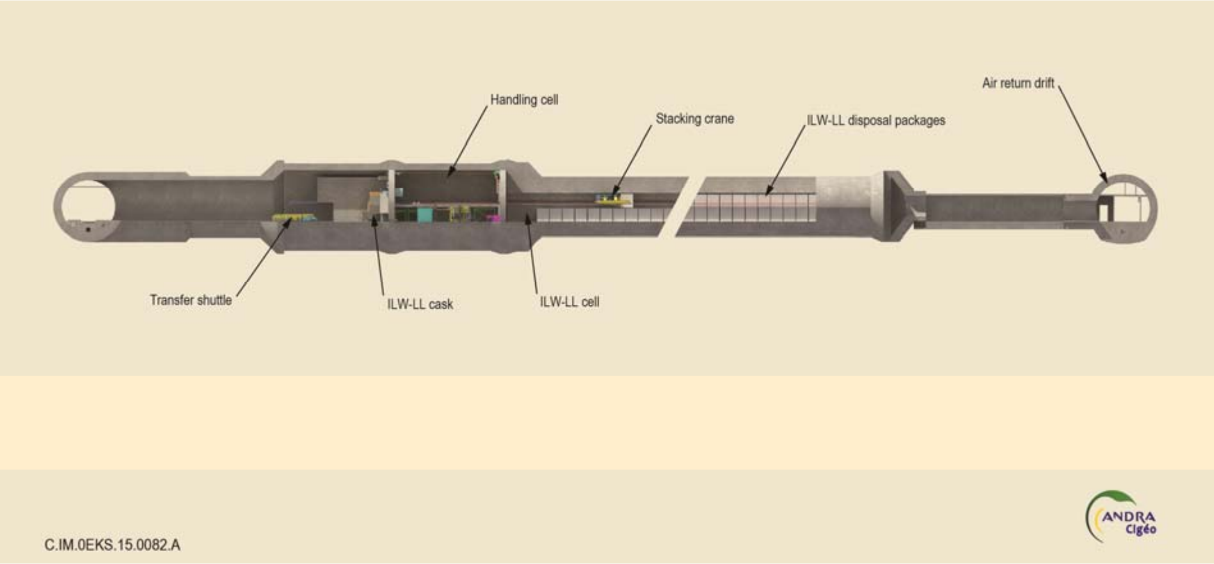


Figure 3.5-26 *Design Principle ILW-LL cell*

<u>Technical solutions for ILW-LL disposal cells</u>

The construction of the ILW-LL disposal cells using a road header machine allows changes of diameter between access drifts, hot cells and disposal cells. The smaller diameter air extraction drift, sized to suit the ventilation requirements, is compatible with the use of a micro-tunnel boring machine. The sizing at this stage assumes excavation with a road header machine with flexible support and a rigid liner.

- support wall: shotcrete, compressible blocks and fully bonded anchor bolts;
- liner ensuring the durability of the structure (and invert);
- infill concrete limiting the void fraction (for post-closure safety), may be precast.

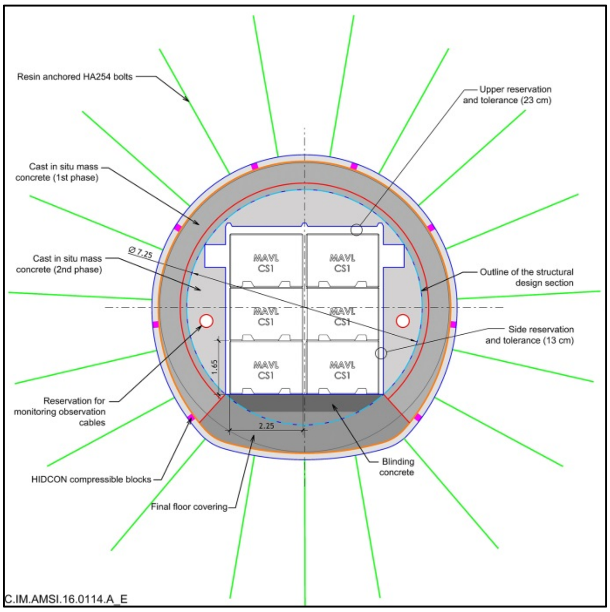


Figure 3.5-27 *Standard section of ILW-LL disposal cell with support and liner. Example of CS1 disposal cells (end of basic engineering design stage)*

The size of the ILW-LL disposal cells depends on the disposal packages it holds. Each type of disposal cell is defined to take account of the rules of co-disposal of different disposal packages and an arrangement of the disposal packages (number of packages per column/level) within the useful area of the disposal cell.

At this stage, the disposal cells contain package arrangements of 1 to 2-3 columns/levels with excavated sections of the order of 17 to 65-70 m². The different disposal cell package filling configurations for packages type CS1 to CS7 are shown in the following cross-sections (at end of basic engineering design).

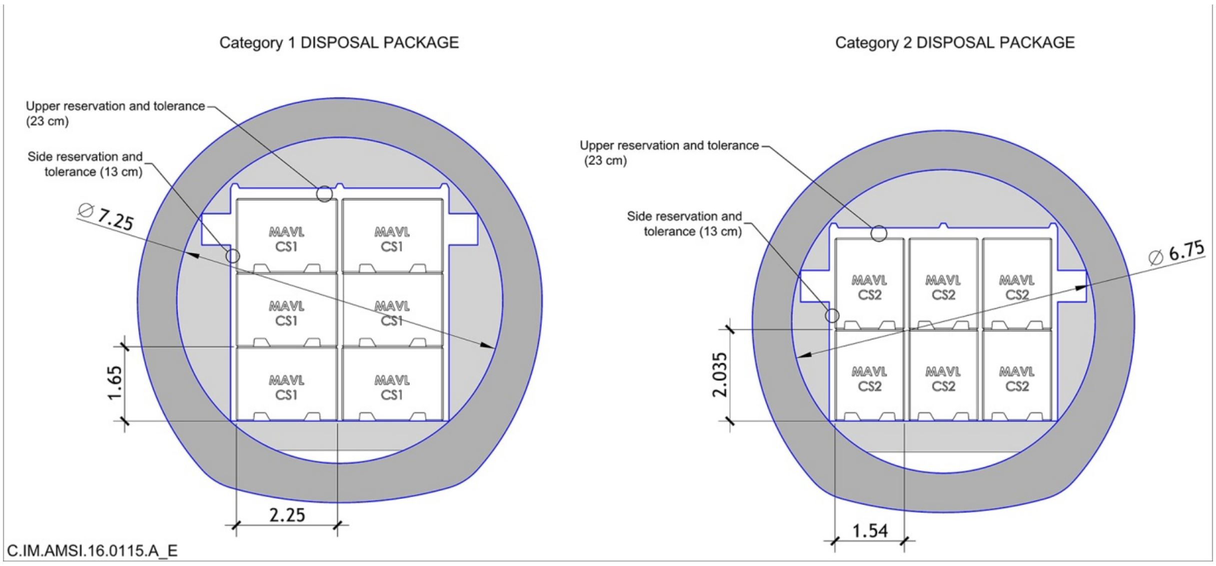


Figure 3.5-28 Filling of disposal cells with packages type CS1 and CS2 (at end of basic engineering design)

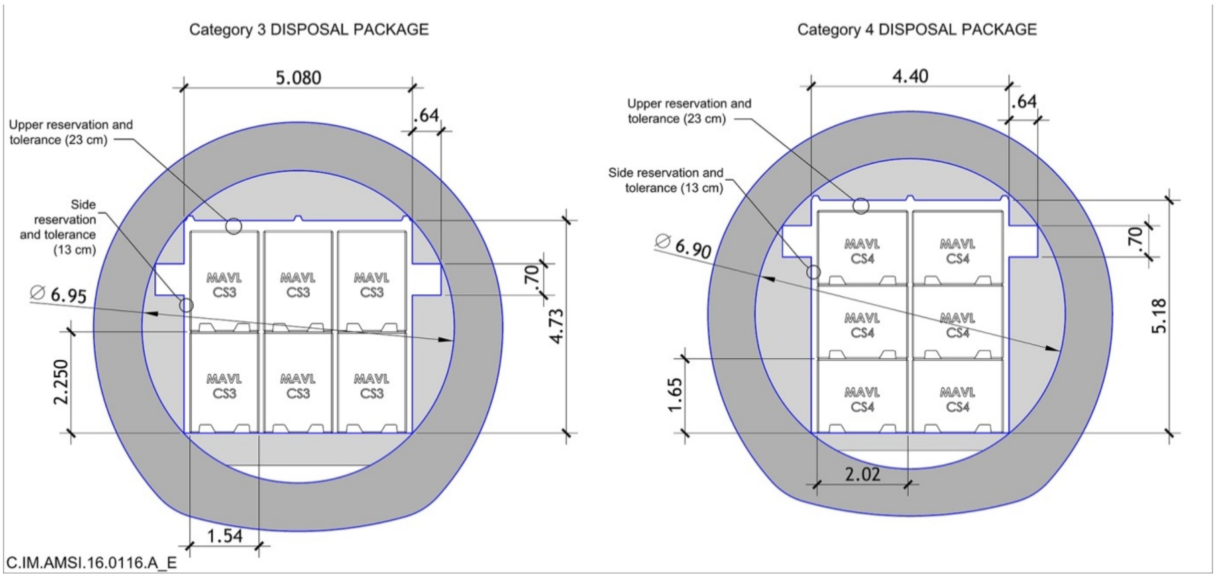


Figure 3.5-29 Filling of disposal cells with packages type CS3 and CS4 (at end of basic design)

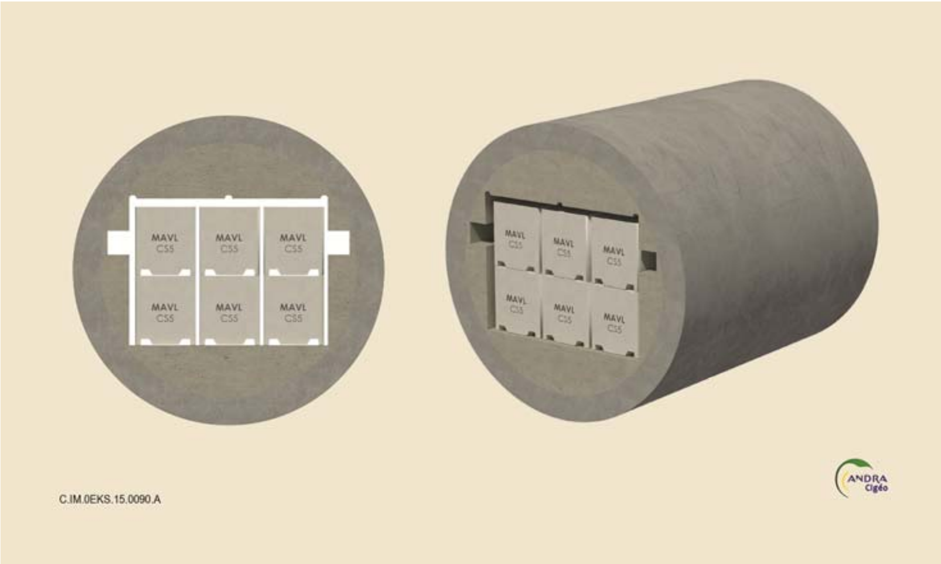


Figure 3.5-30 Filling of disposal cells with packages type CS5 (at end of basic engineering design)

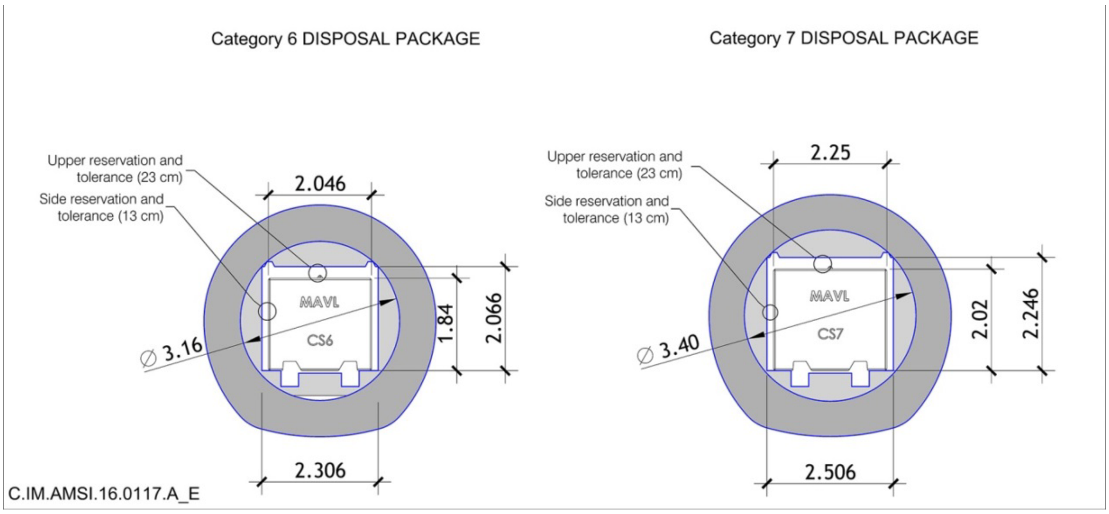


Figure 3.5-31 Filling of disposal cells with packages type CS6 and CS7 (at end of basic engineering design)

3.5.8.8 Optimisations of ILW-LL disposal cells considered

Based on the current design:

- the justified optimisation of the methods of definition, sizing and constructing the support walls-liners remains a constant objective and is the subject of various studies;
- studies aimed at reducing the distance between disposal cells, currently 5 diameters, will be conducted on the basis of the shortest distance that guarantees the mechanical stability of the ILW-LL zone while at the same time limiting physical-chemical interaction for which a minimum distance of 30 metres is adopted;
- the infill concrete to comply with the post-closure void fraction, could be replaced with a powdery material, for example produced with the clay rock (while complying with the void fraction requirement);

- the direct disposal solution (solution no. 3) in the section dealing with waste packages (see section in Chapter 1 of this volume) consists in storing primary waste packages directly in the disposal cells without first being placed in disposal containers, providing they meet the specified requirements. Studies undertaken during the detailed engineering design phase of the project will aim to identify those packages suitable for direct disposal associated with technical disposal solutions that are justified with respect to safety, technical and economic feasibility and industrial safety criteria. It is intended to take account of this optimisation as early as phase T1;
- An objective of optimisation of the ILW-LL disposal cells and disposal section is being examined as part of a densification of the repository and thus a reduction in the number of disposal cells, by modifying the package arrangement and increasing the number of columns and levels from 1 to 3-4 columns/levels. The excavated sections associated with this densification are of the order of 17 to 110 m². The compliance of these disposal cell configurations with the different criteria stated above will need to be justified. A demonstration ILW-LL disposal cell of approximately 110 m² is planned at the industrial pilot phase. It is planned to take account of this optimisation after phase T1,
- A change of the chosen excavation methods is envisaged, with the use of a full-face tunnel boring machine. It requires that the functions of the hot cell be contained within a single diameter equal to that of the access drift and the disposal cell. This solution, which is favourable for the safety of the construction works, simplifies and optimises the placing of support walls and liners.

3.5.8.9 Principle of ILW-LL disposal section deployment

Based on the waste package flow schedule, the deployment of the disposal cells takes account of the geometric disposal options of the different disposal waste packages. The current options for grouping waste packages are CS1 with CS5, CS4 with CS5, and CS2 with CS3. Six ILW-LL package physical-chemical categories

Plus a seventh category of waste containing small amounts of sodium-containing waste. The design of Cigeo is based on the separation of waste with different physical-chemical characteristics.

Based on elements of co-disposal and the waste package delivery flows, a schedule of deployment of the ILW-LL repository zone is presented below.

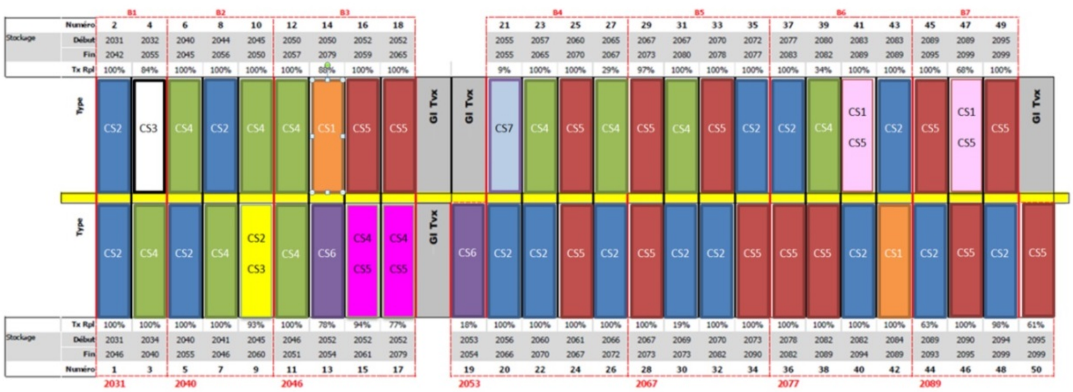


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Figure 3.5-32 ILW-LL disposal cell deployment schedule (end of basic engineering design)

3.5.8.10 Interfaces between the construction zone and the operating zone in the ILW-LL disposal section: Coordinated working

The works constructed in the ILW-LL disposal section in phase T1 are the connecting drifts, disposal cell access drifts, the air return drift and 4 (or 5) disposal cells to match the disposal cell requirement at the end of phase T1.

The next stages of the expansion of the ILW-LL disposal section will proceed in parallel with its operation. The ILW-LL disposal section is deployed using the "advancing" method. In other words the disposal cells will constructed then operated moving away from the operating logistical support zone. The disposal cells in operation advance behind the disposal cells under construction. The interfaces between the construction zone and the operating zone in the ILW-LL disposal section are shown schematically below:

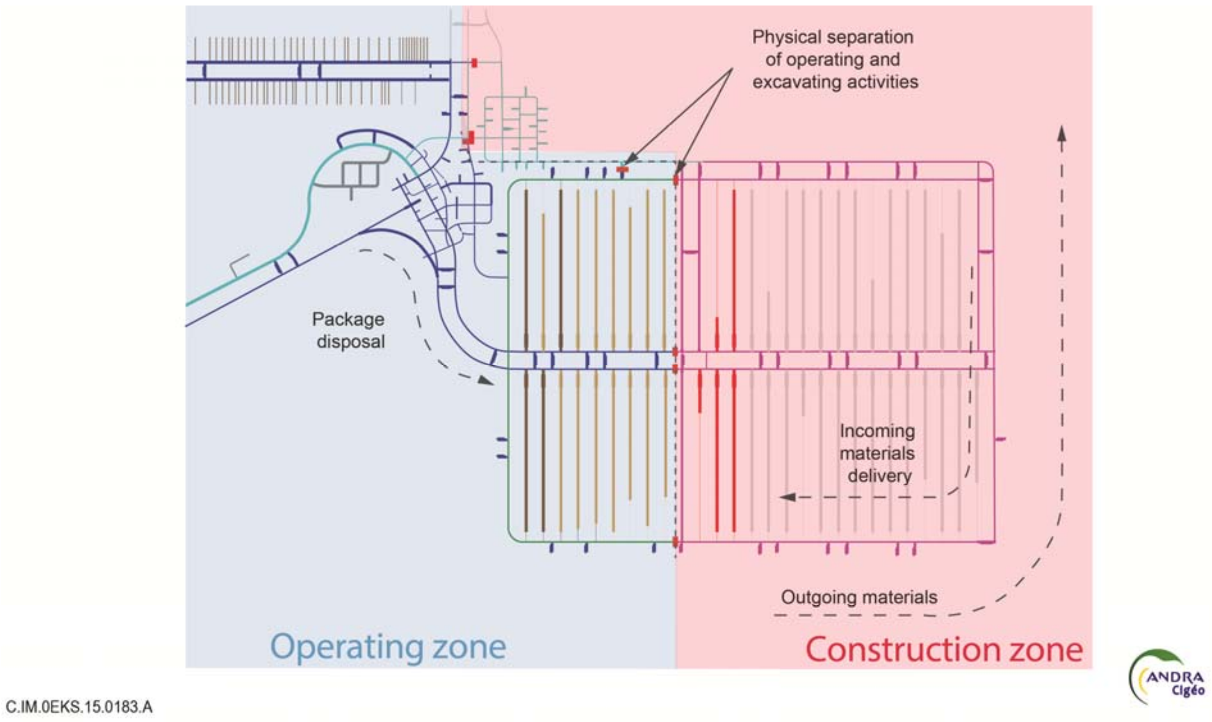


Figure 3.5-33 ILW-LL disposal section - interfaces between construction and operating zones

The repository deployment process will be as follows:

- initial state: civil engineering construction of the structures of the phase to be deployed;
- the operating phase (phase P) is isolated from the zone under construction and testing (P+1) in accordance with the operational compartmentation requirements under normal conditions, namely:
  - ✓ physical separation and personnel air lock in connecting drift;
  - ✓ physical separation and personnel and vehicle air locks in air return drift,

Deployment then comprises the following stages:

- stage 1: delivery and installation of equipment on site;
- stage 2: connection of HV range "A" network to the main operational network;
- stage 3: powering-up of equipment and connection to the network: no impact on operation;
- stage 4: testing and qualification of phase 2 (isolated mode): no impact on operation;
- stage 5: Switching of test zone to operation;
- Stage 6: Comprehensive tests.

The figure below shows a possible plan of deployment between the construction, fitting-out and operating activities.

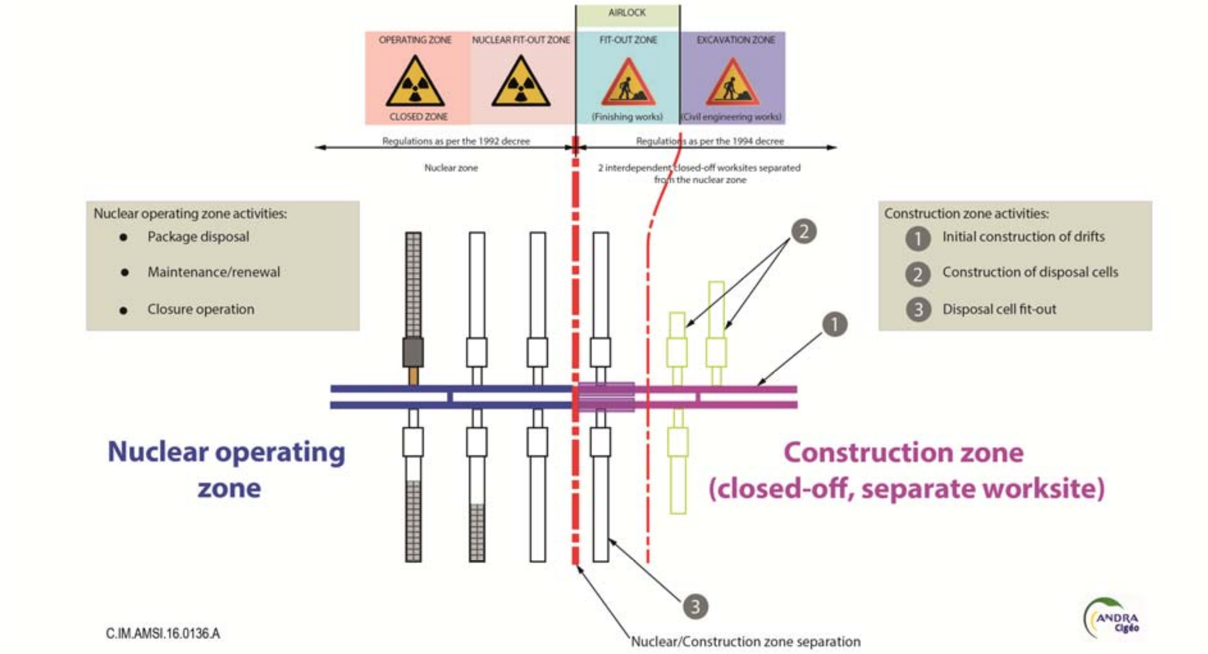


Figure 3.5-34 Illustration a possible plan of deployment between the construction, fitting-out and operating activities

3.5.9 Transfer and disposal in the ILW-LL disposal cells

The ILW-LL package repository zone comprises three sections:

- an access drift within which the docking shuttle runs and in which the cask is docked;
- a hot cell in which the packages are removed from the cask and moved into position for pick-up by the stacking bridge crane (or stacking cart for CS6/CS7);
- the disposal cell.

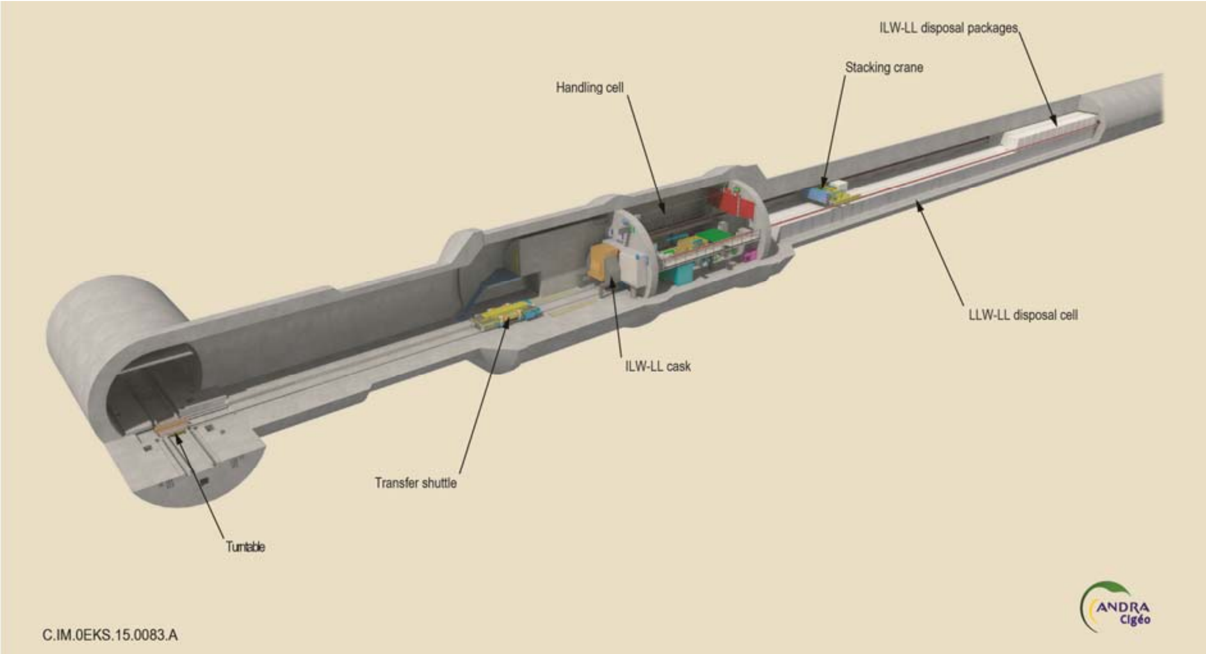
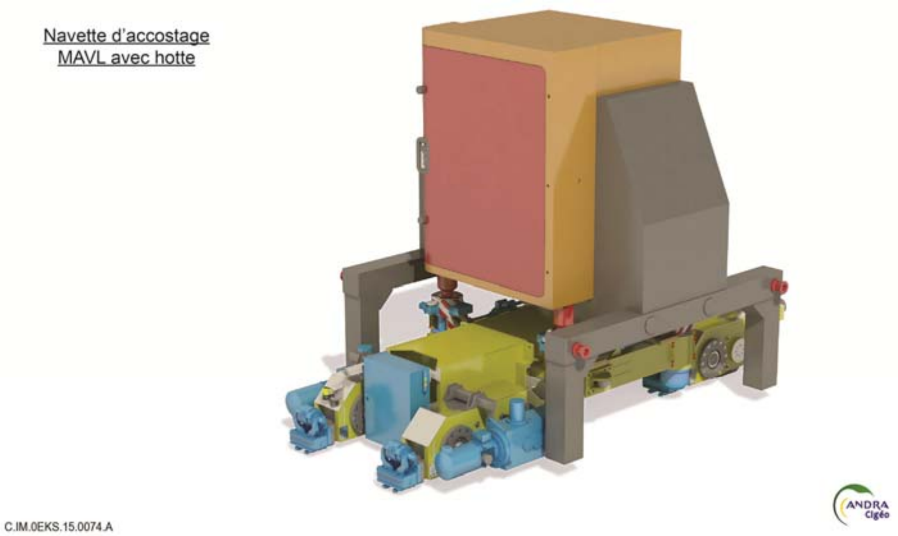


Figure 3.5-35 Package CS1 to CS5 disposal cell

3.5.9.1 Cask transfer in the ILW-LL disposal cell access drifts

At the intersections between the connecting drift and the access drift, the ILW-LL casks are transferred onto under-travelling shuttles which precisely and slowly transfer them to the docking facades. They then set down the casks on the docking tables.



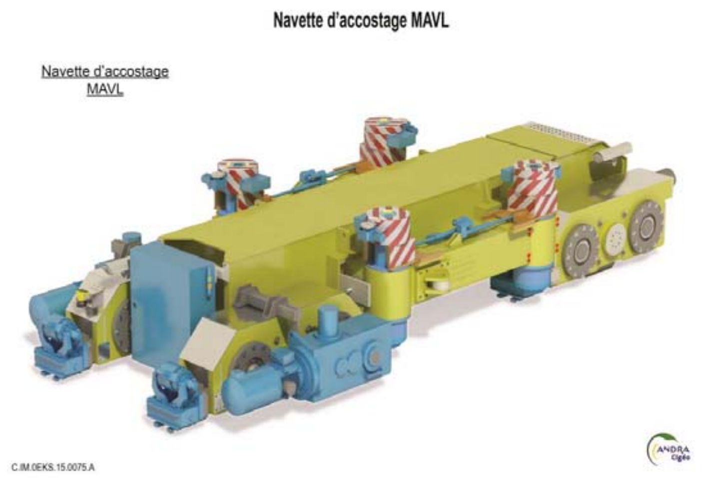


Figure 3.5-36 ILW-LL docking shuttles

The ILW-LL cask docking systems are the same as those of the surface facilities. The ILW-LL cask is set down by the ILW-LL shuttle on the docking table, which completes the docking of the cask against the facade. Fixed concrete pads situated against the docking facade serve to prevent the cask dropping in the event of fire while it is in the docked position.

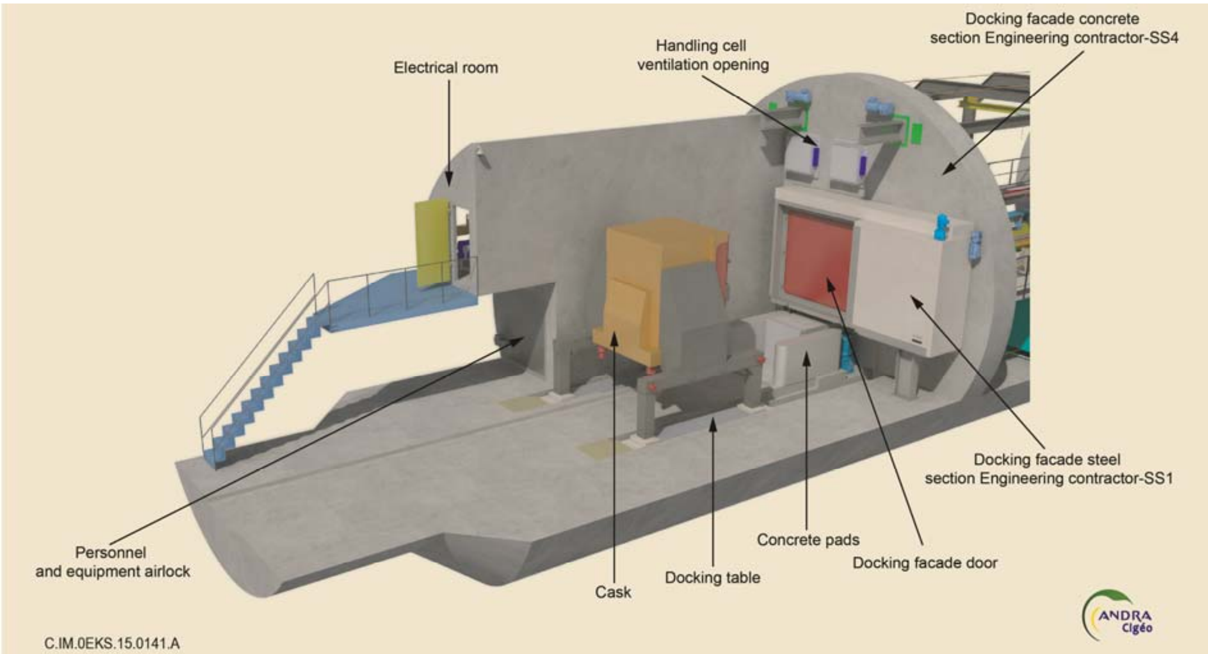


Figure 3.5-37 Movement of the docking table towards the facade

There are two different docking facade geometries:

- one for casks type CS5 and CS1, 4, 6, 7;
- another for casks type CS2 and 3.

The docking takes are the same. As at the surface, the docking facade comprises a concrete part and a steel part.

An air lock on the side of the docking facade enables the circulation of personnel and equipment. The electrical room, which supplies power to and enables the control of the ILW-LL shuttles, as well as all the equipment in the hot cell, is located above the air lock.

The upper part of the docking facade supports the ILW-LL hot cell ventilation penetrations. The facade also serves to maintain the static seal between the access drift and the hot cell.

The packages are placed in the ILW-LL disposal cells via a hot cell in which the disposal packages are unloaded from the cask and placed in the disposal cell.

The ILW-LL disposal packages are handled in the hot cell by different handling equipment according to the type of package in the disposal cell (stacked or on one level). As far as is possible, the drive systems are remotely located outside the hot cell, on the docking facade for easier maintenance and to reduce the heat loads in the hot cell.

For ILW-LL disposal package types 1 to 5, the packages are unloaded from the cask by a receiving table with a transfer carriage and transferred onto to a lift table to be set at the correct height for the layer on which they will be placed. They are then picked-up by the stacking crane and transferred to their emplacement position within the disposal cell.

3.5.9.2 Stacking crane for packages CS1 to CS5

The stacking crane arrange the disposal packages in several levels and several rows (CS 1 and 4: 2 rows on 3 levels; CS 2, 3, 5: 3 rows on 2 levels).

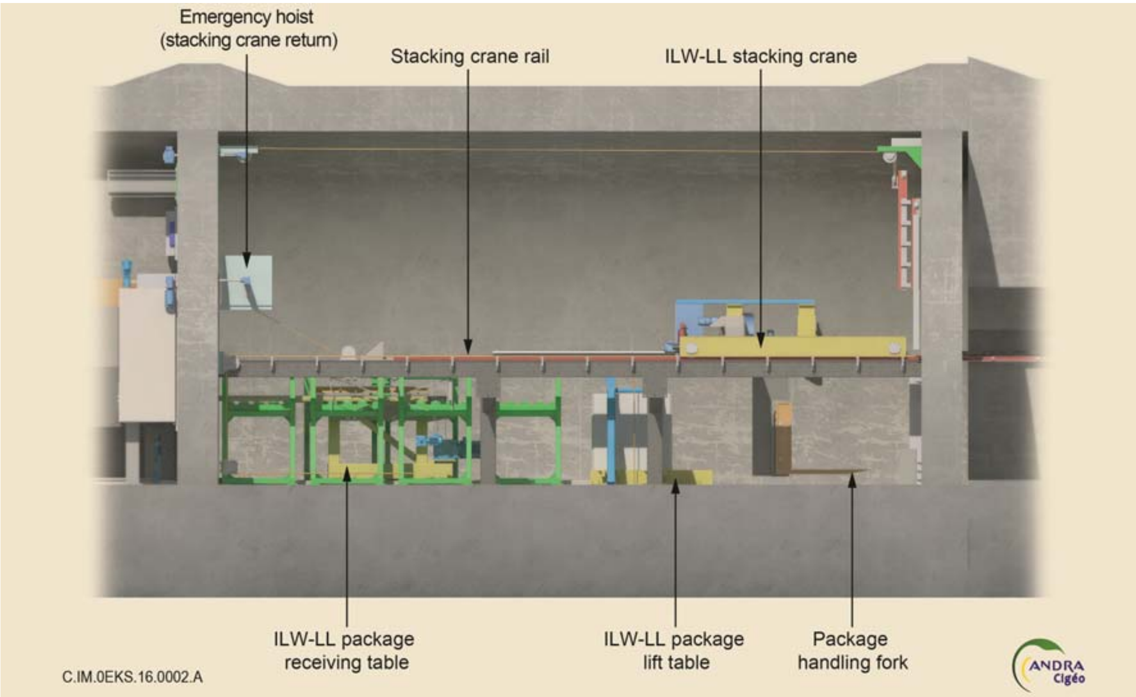


Figure 3.5-38 illustration of a hot cell and stacking crane

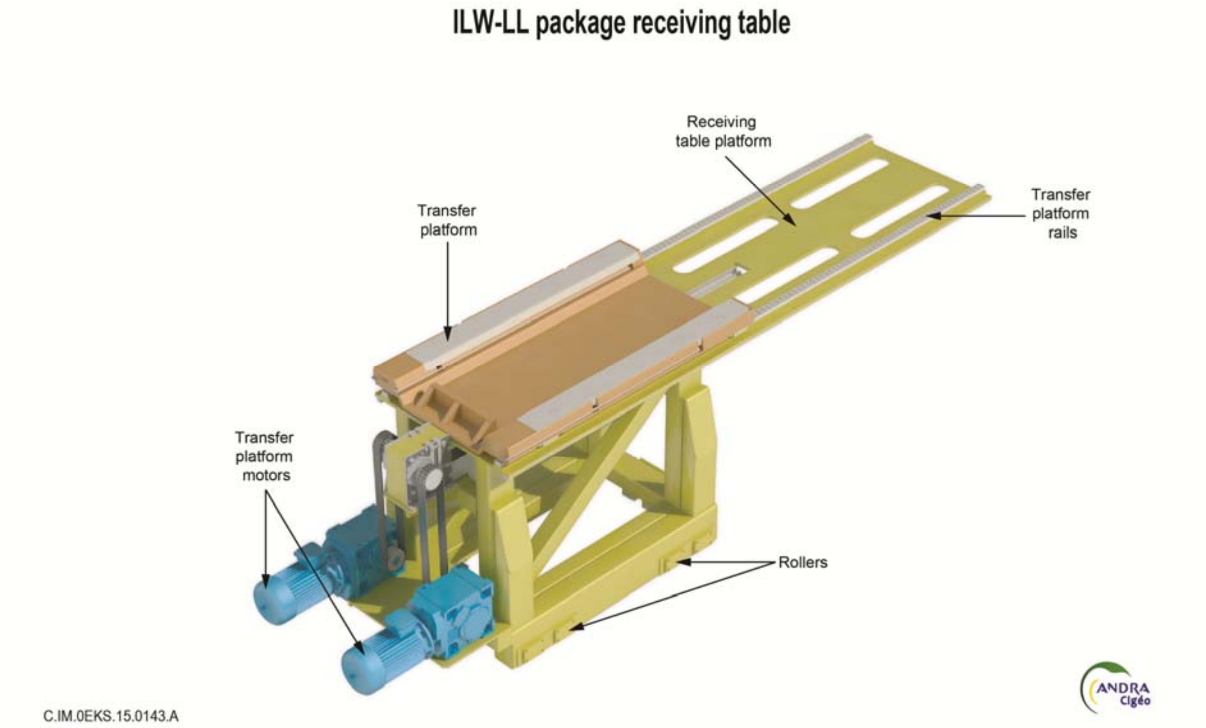


Figure 3.5-39 Receiving table

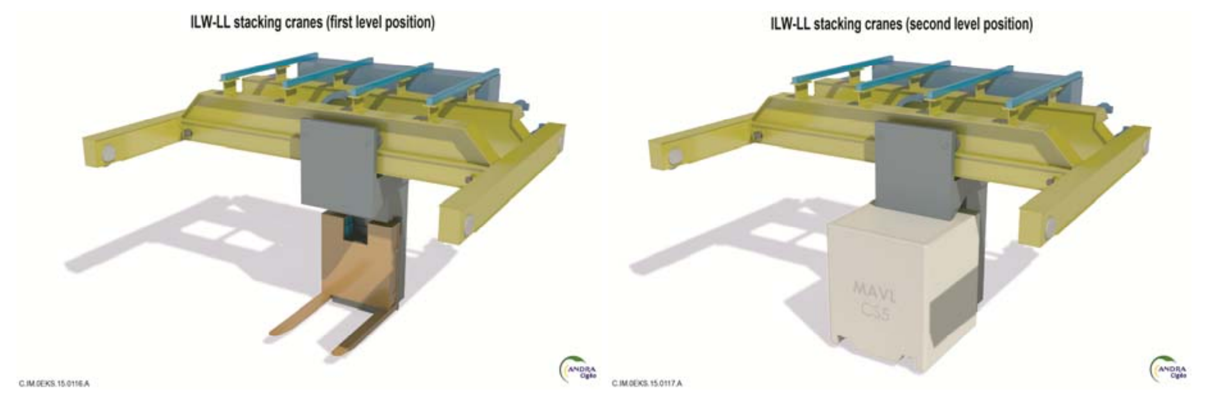


Figure 3.5-40 Stacking crane

After filling the bottom level of each disposal cell, decking is placed between the lift table and the shielding door (described below), to limit the potential drop height of the disposal package. The handling height of the stacking crane is adjusted by removing a spacer. The vertical travel of this transfer system is small. The stacking crane lifts the disposal packages to carry them just clear of the floor or of the previously emplaced disposal packages (or the decking). The drop height is adhered to in all cases.

A multi-turn take-up reel supplies power to the stacking crane over a useful disposal cell length of 500 m. It is installed within a fire-proofed protective casing, enabling the take-up reel to be quenched by an extinguishing agent upon detection of fire.

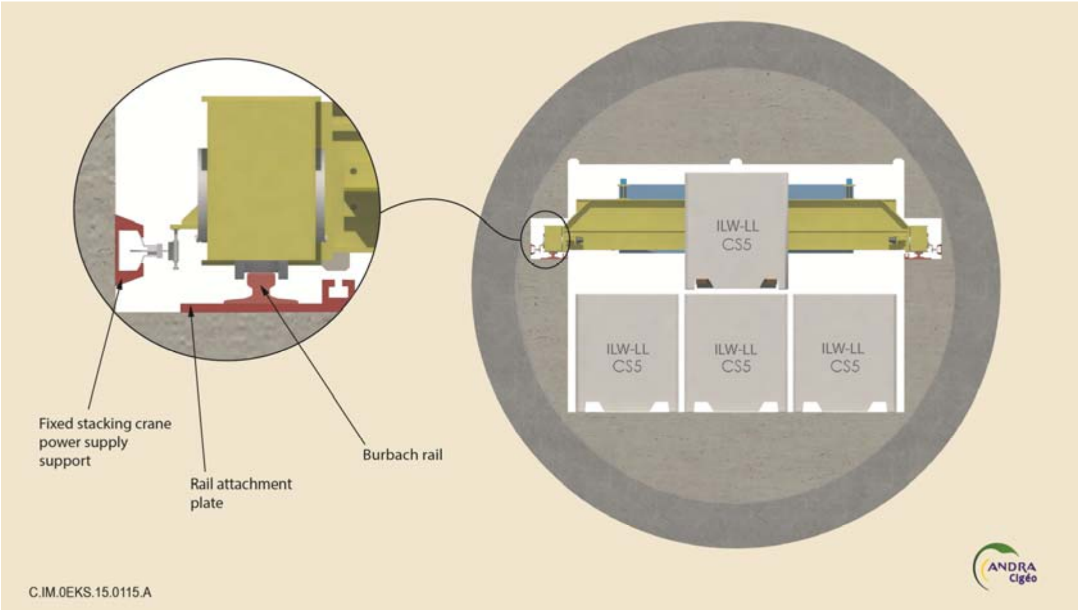


Figure 3.5-41 Stacking crane in the disposal cell – top level

Special provision: A concrete wall constructed as the filling of the package layers progresses, limits the drop height between the hot cell and the useful zone of the of the disposal cell, and also isolates the radioactivity from the filled disposal cell for dismantling of the hot cell equipment.

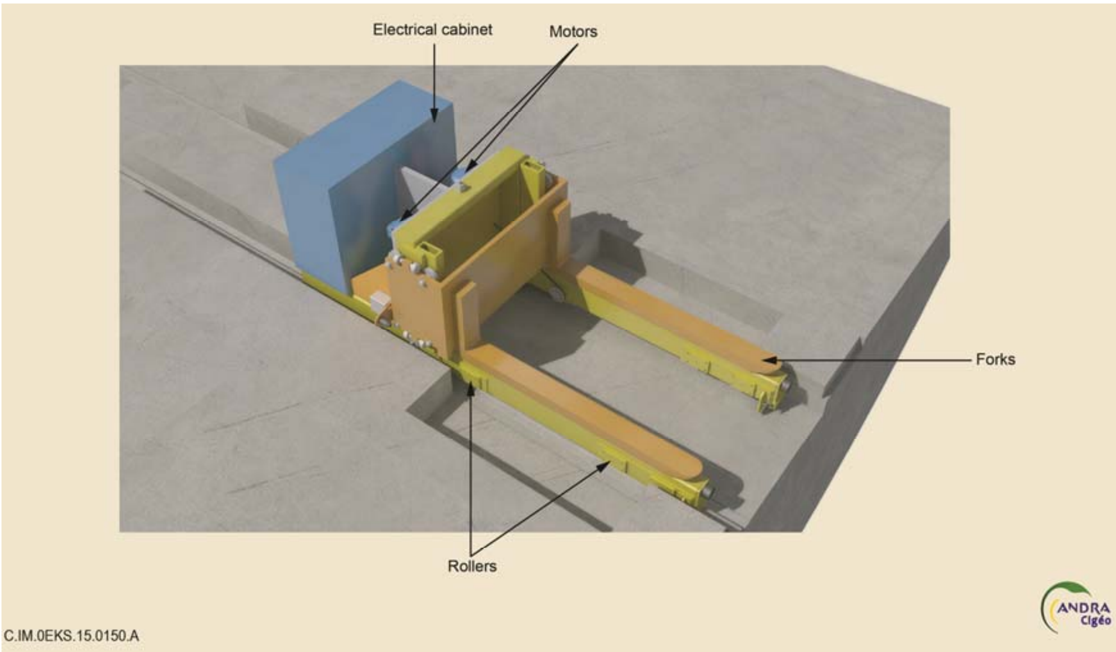


Figure 3.5-42 Storing cart for CS6 to CS7

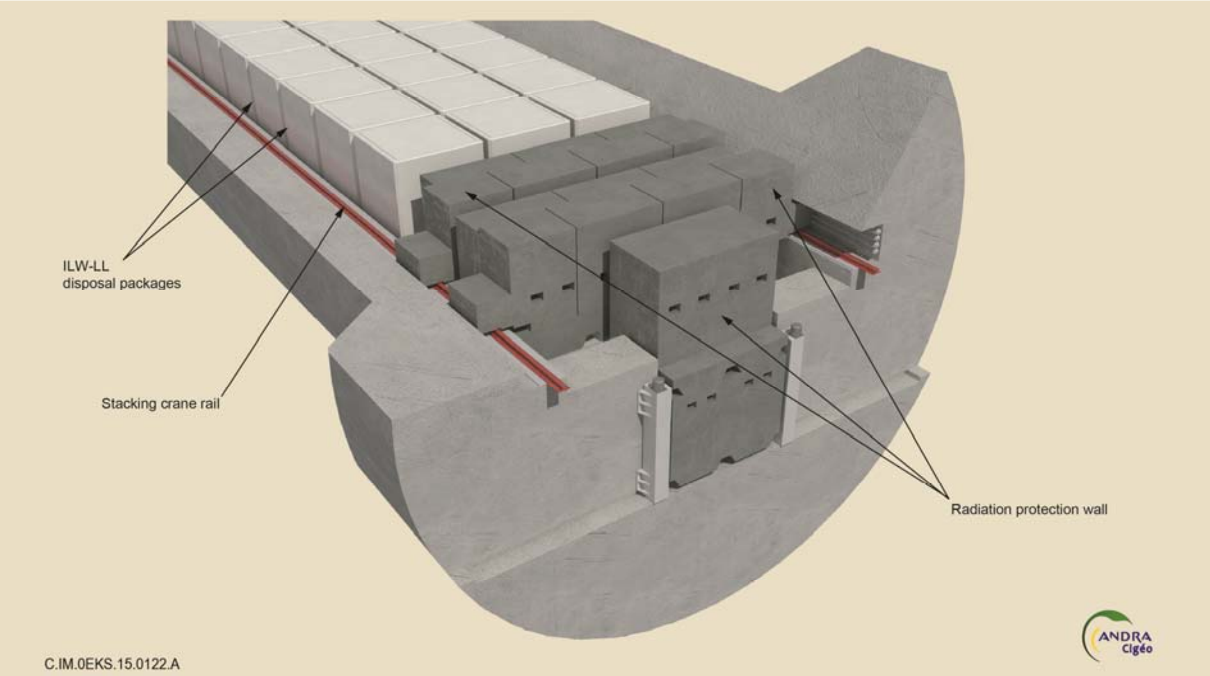


Figure 3.5-43 Disposal cell closure – Concrete block

3.5.9.3 Storing cart for packages CS6 and CS7

For ILW-LL disposal package types 6 to 7, the packages are unloaded from the cask by a receiving table with a transfer carriage and transferred onto to the lift table. They are then picked-up by a storing cart to be carried to their emplacement position within the disposal cell.

The storing cart can only place disposal packages in one row and on one level. As for the other transfer systems, the disposal package is carried at a very low height

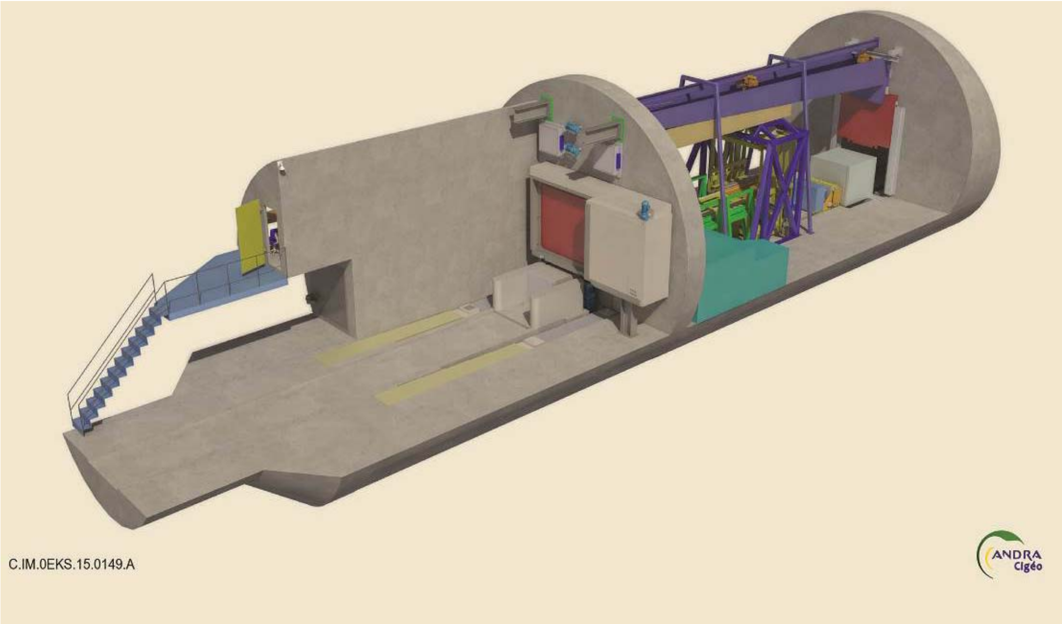


Figure 3.5-44 Package C6 and C7 disposal cell

Prior to dismantling the equipment, when the disposal cells are filled, radiological shielding in the form of a concrete block wall is constructed at the head of the usable part of the disposal cell between the last row of packages and the hot cell shield door

3.5.9.4 Radiation protection door

A movable screen consisting of three panels, hereafter referred to as the "shielding door", is lowered between the disposal cell and the hot cell. This shields the personnel working within the hot cell against radiation from the disposal packages inside the disposal cell. This shielding door does not perform any containment function: by virtue of its design, it must allow through ventilation air from the hot cell to the disposal cell.

The shielding door is designed to give Dose Equivalent Rate at contact of 25µSv/h.

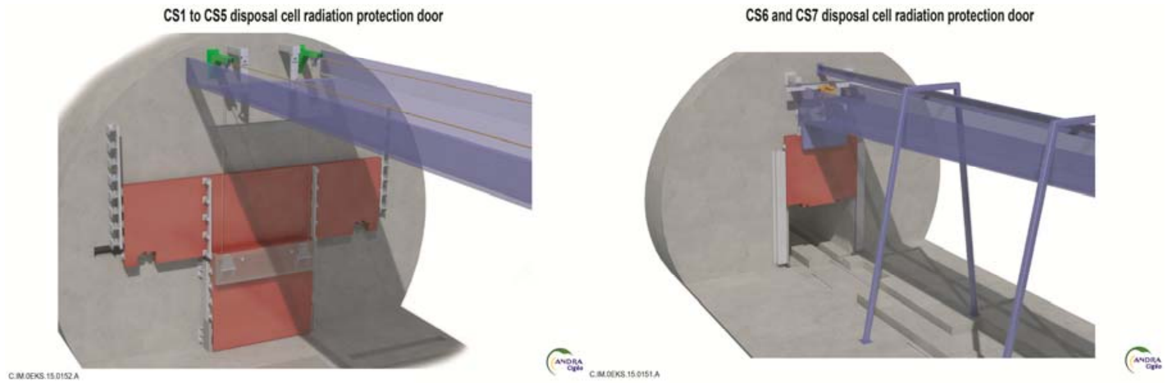


Figure 3.5-45 Shielding door (on the left for CS1 to CS5 and on the right for CS6 and CS7)

The ventilation system is based on a transfer of air from the hot cell towards the disposal cell via penetrations left unobstructed by the radiation shield (radiation maze without leakoff line). It serves only to protect the personnel against ionising radiation during maintenance and to protect the equipment against radiation from the disposal cell during waiting phases.

3.5.9.1 General principles of operation of the ILW-LL disposal section

The operation of the underground facility is carried out as follows:

- In the lower station and logistics support zone*:*
  - ✓ pick-up of full cask from the ramp transfer system by the an underground cart;
  - ✓ turning of cart on the logistics support zone turntables;
  - ✓ transfer of cart with full cask to the connecting drift leading to the destination disposal section of the package.
- Within the ILW-LL disposal section*:*
  - ✓ setting-down of cask opposite the access drift of the destination disposal cell;
  - ✓ turning of rail turntable;
  - ✓ pick-up of ILW-LL cask by the ILW-LL shuttle;
  - ✓ setting-down of ILW-LL cask on the docking table;
  - ✓ docking of ILW-LL cask with the docking facade.

- In the hot cell and the ILW-LL disposal cell:
  - ✓ opening of cask and docking facade;
  - ✓ removal of package from the cask by the transfer carriage;
  - ✓ transfer of package onto lift;
  - ✓ raising of package to required height and pick-up by the stacking crane;
  - ✓ packaged positioned in the disposal cell by the stacking crane.

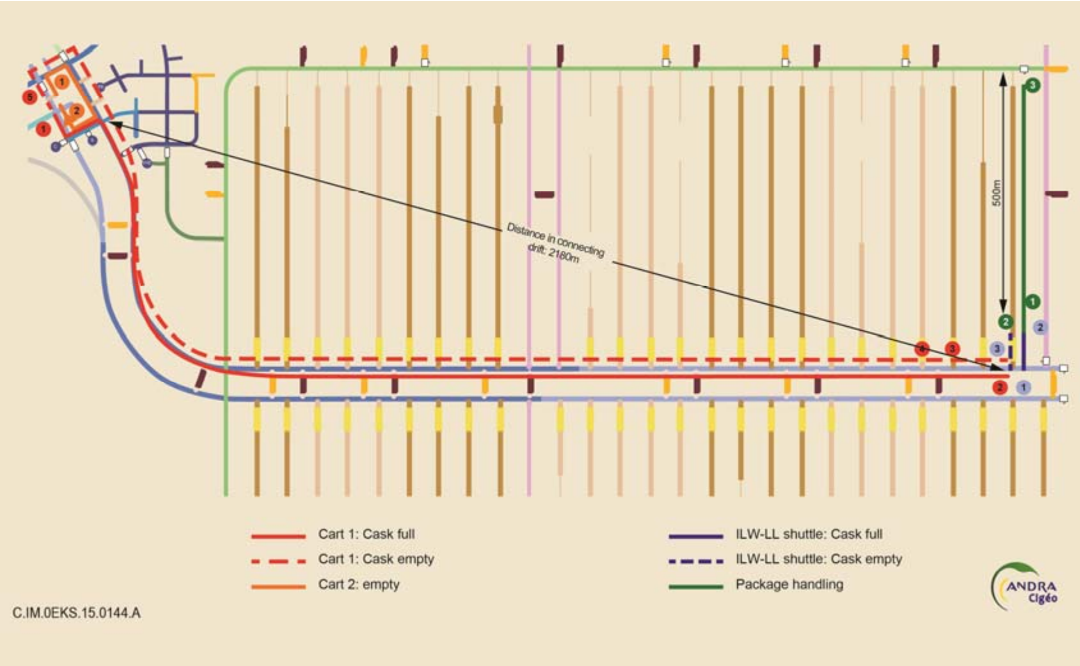


Figure 3.5-46 Diagram of the ILW-LL underground transfer cycle

3.5.9.2 Special provisions in the ILW-LL disposal cells

Package retrievability is ensured using the same equipment at for emplacement. However, these are supplemented by a contamination control system and a system for fixing any such contamination. Contamination control is performed with swabs using a remote-controlled manipulator arm. It is fixed by means of a spray treatment.

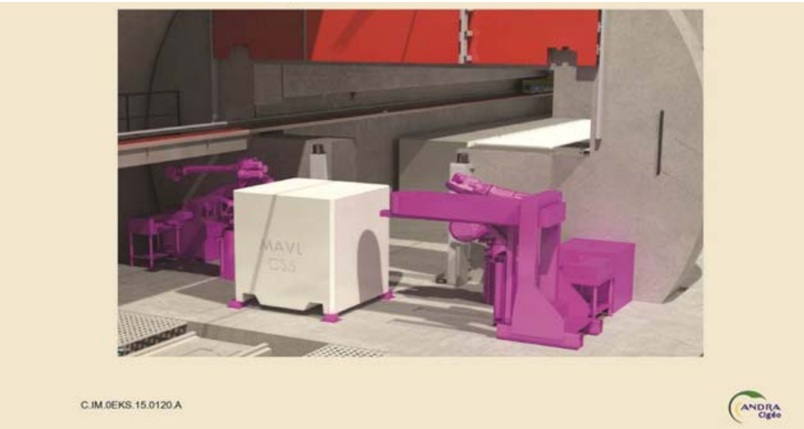


Figure 3.5-47 Contamination control and treatment equipment

3.5.10 **HLW repository zones**

3.5.10.1 Main design requirements of the HLW disposal sections and cells

It should be noted that the requirements and data taken into account for the design of the repository zones are directly associated with the post-closure safety objectives listed in the DOS-AF.

Design criteria: (based on the reference design adopted at the end of the basic engineering design stage)

- disposal cells are sub-horizontal micro-bores with a slope of 1% to 2 % with the lower end oriented towards the access drift to collect any possible effluent;
- the HLW and HLW0 disposal cells are dead-end cells;
- the length of the HLW disposal cells will be established in particular according to the risk of deflection of the sleeving, so as to meet the package handling straightness requirements;
- in keeping with the post-closure safety requirements, the length of the HLW disposal cell is greater than 50 m. At this stage:
  - ✓ the length of the exothermic HLW disposal cells is of the order of 100 m;
  - ✓ the length of the moderately-exothermic HLW disposal cells is of the order of 80 m.
- the disposal cells are oriented according to the direction of major stress of the Callovo-Oxfordian formation,
- sleeving:
  - ✓ the sleeving of the HLW disposal cells are made of low-carbon steel;
  - ✓ the mechanical stability of the HLW disposal cells is ensured by a sleeve. It must be ensured over the period of reversibility;
  - ✓ the sleeve must provide a minimum of 500 years' resistance (thermal and thermo-mechanical stresses, corrosion, uneven loading) in order comply with the post-closure safety requirements;
  - ✓ minimum 25 mm thick "sour-service" oil-industry grade sleeve, with a diameter that is a multiple of 2 inches, in accordance with industrial standards;
  - ✓ resistance to maximum geostatic stresses, corrosion: 10μm per year reduction in thickness over 500 years.

Requirements linked to the industrial architecture:

- the most exothermic HLW disposal sections are grouped together within a same zone, to the North of the logistical support zones (zone of interest for detailed reconnaissance);
- the moderately-exothermic HLW0 zone comprises one disposal section.
- two options:
  - ✓ the disposal section can be constructed in a single phase (2 connecting drifts) and then made available for operation;
  - ✓ the disposal section is constructed in several phases to meet the industrial safety requirements (possible construction of an emergency drift between the two connecting drifts).
- the highly-exothermic HLW zone is constructed in several phases (one phase per disposal section). In order to maintain the separation between construction and operation, each disposal section is fully constructed and fitted-out prior to entry into operation;
- HLW1 and HLW2 waste packages will be emplaced in turn;
- the minimum connecting drift buffer distance between the HLW0 disposal section and the surface-to-bottom connections shall be taken as equal to 300 metres (disposal section in which mobile, long-lived radionuclide activity is relatively low: moderately exothermic HLW);
- the minimum connecting drift distance between the ILW-LL/HLW (excluding HLW0) disposal sections and the surface-to-bottom connections shall be taken as equal to 500 metres (disposal sections in which the mobile, long-lived radionuclide activity is high: highly exothermic HLW and ILW-LL).

Thermo-hydro-mechanical design conditions of HLW disposal sections

To justify the post-closure safety of the repository at the disposal section level, a thermo-hydro-mechanical design of the HLW disposal sections is performed, taking account of:

- the heat induced by the different types of HLW and the diffusion of the heat in the clay rock and the thermal decay associated with the radioactive decay which is a function of the inventory and the preliminary storage time;
- the major horizontal stress perpendicular to the centreline of the access drifts;
- the hydro-mechanical response of the clay rock to temperature increase (changes in interstitial pressure and effective stress with respect to mechanical strength) and the mechanical response of the clay rock to the access drift boring operations (strain, fractures, behaviour of the damaged zone);
- ventilation of the drifts during the operating period and any changes in air flowrate over the successive construction and operating phases and while awaiting closure,

For information, for the continuation of the detailed engineering design, the following design data are used, based on models, with conservative thresholds for the failure criteria (Rt=0):

Table 3.5-1 Distances between centres of moderately exothermic HLW disposal cells approximately 80 m long

Waste package family		Heat rating (watts per package)	Number of packages per disposal cell	Number of disposal cells	Distance between cells Px (m)
CEA-1070, CEA-1080, CEA-350, CEA-1500	AVM glass, Atalante glass, HLW sources	193	64	13	51
		132	64	13	36
		77	64	19	22
		33	64	5	9.5
COG-150	UMo glass	40	45	20	11.5
CEA-200, CEA-1190	Piver glass and laboratory glassware	30		2	8.5

Table 3.5-2 Distance between cells for disposal of highly exothermic HLW approximately 100m long

	Waste package family	Number of packages (PIGD vD)	Age of packages and thermal output on disposal in the repository	Number of packages per disposal cell	Number of cells	Distance between cells, Px (m)
Reference timeline (2075-2140)	COG-140 COG-810 COG-820 COG-850 COG-860 COG-870 COG-880 COG-890 COG-900 COG-150	**7721**	85 years (275 W per package)	44	180 (of which 4 reference cells)	33
	COG-800	**19010**	85 years (345 W per package)	38	501	36
	COG-200 COG-830	**15888**	85 years (365 W per package)	34	472 (of which 4 reference cells)	51
		9268	70 years (448 W per package)	29	320	45

- Distance between two disposal cells containing packages of different heat ratings is equal to the distance required corresponding to the more exothermic disposal cell of the two;

- the thermal requirements dictate the distance of 30m between the back of disposal cells within a same HLW disposal section and between different HLW disposal sections;
- the access drifts and cross cuts in the repository zone are subject to thermo-hydro-mechanical design. Technical solutions enable to take into account the expansion of the liners, with the use of compressible blocks in the liner, for example.

Monitoring observations*:*

- In order to enable the tracking of certain parameters requiring monitoring devices, two HLW disposal cells will be constructed, which are representative of the disposal cells subsequently constructed, from which the packages will ultimately be removed to be emplaced in other disposal cells.

3.5.10.2 HLW disposal cells

The HLW disposal cells comply with the design principles which serve to justify the performance of the structures in operation and after closure.

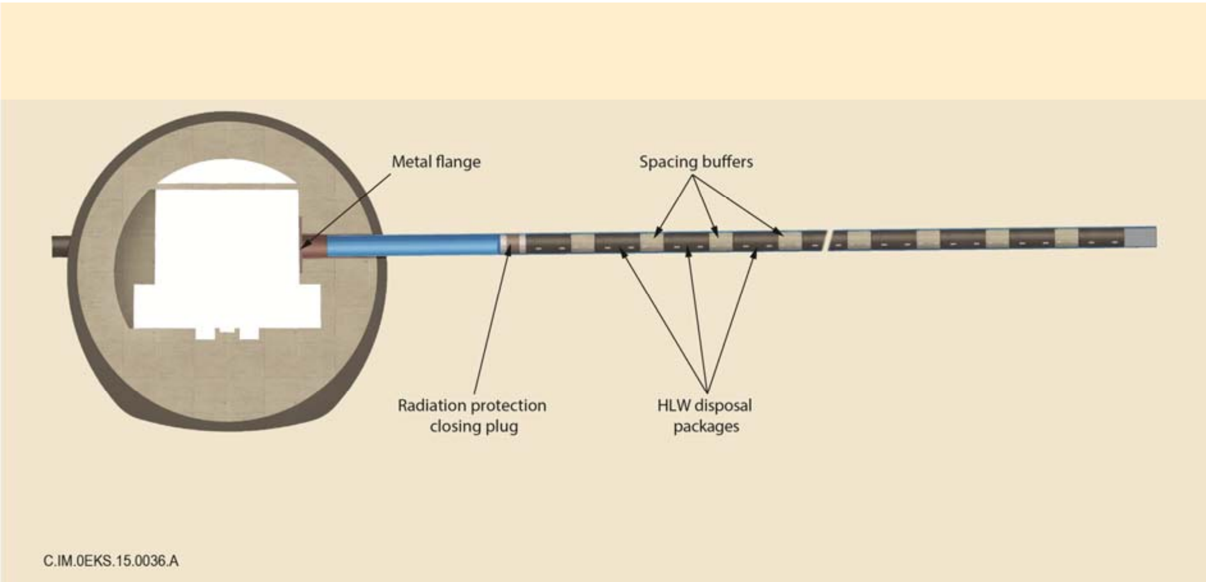


Figure 3.5-48 Cross section through a HLW1/HLW2 disposal cell: shown here at the end of loading (illustration from end of basic engineering design stage)

The reference design of the disposal cell adopts a metal sleeve with a primary waste package (CSD-V) placed in a metal disposal container,

- the disposal cells contain disposal packages and (spacers if applicable[49]);
- the sleeving has a minimum thickness of 25 mm, it has a diameter of the order of 700 mm;
- the disposal cell comprises a cell head and a usable disposal part;
- during operation, the cell head consists of a flange and a radiation protection plug, while awaiting the final closure of the disposal cell,
- the annular gap between the sleeve and the clay rock is filled with a material that imposes corrosion-limiting environmental conditions (cement-based grout, etc.).

At this stage, based on the information acquired in the Underground Research Laboratory, the total length of the HLW0 disposal cell is 80 m. A test on a representative disposal cell is scheduled in 2017 at the Underground Research Laboratory. In view of the time available for justifying the design before

[49] The spacing buffers serve to control the thermal output of a disposal cell as part of the thermal design of the repository zone, the ultimate objective being to minimise their use.

construction and operation of the HWL1/HWL2 zone, in particular based on the experience gained with zone HLW0, the total length adopted for the HLW disposal cell is100 m.

Enhancements to the HLW disposal cell design capable of performing identical functions will be studied. They could, in particular, be based on a design using non-metallic components or incorporating corrosion-prevention measures (e.g. using ceramic materials).

3.5.10.3 HLW0 repository zone

The HLW0 repository zone is connected to the construction and operating logistical support zones by construction and operating connecting drifts and access drifts.

The moderately exothermic HLW0 disposal section will be constructed and operated for several decades before the more highly exothermic HWL1/2 zone. The disposal section, representing approximately 5 % of the total number of disposal cells, is a pilot for the HLW part of the repository. It will provide operating experience feedback relating to the construction and operation of the HLW disposal cells. Based on a network of thermo-hydro-mechanical parameter acquisition and monitoring instruments, this pilot HLW disposal section which confirms and clarifies the durability of the infrastructure drifts and the working of the ventilation, allows the finalisation of the HLW repository design.

Two options are envisaged:

- The disposal section can be constructed in a single phase (2 connecting drifts) and then made available for operation,
- The disposal section is constructed in several phases to meet the safety requirements (possible construction of an emergency drift between the two connecting drifts).

In the solution presented below, the HLW0 disposal section is constructed in a single phase comprising two access drifts. It is handed over for operation upon completion.

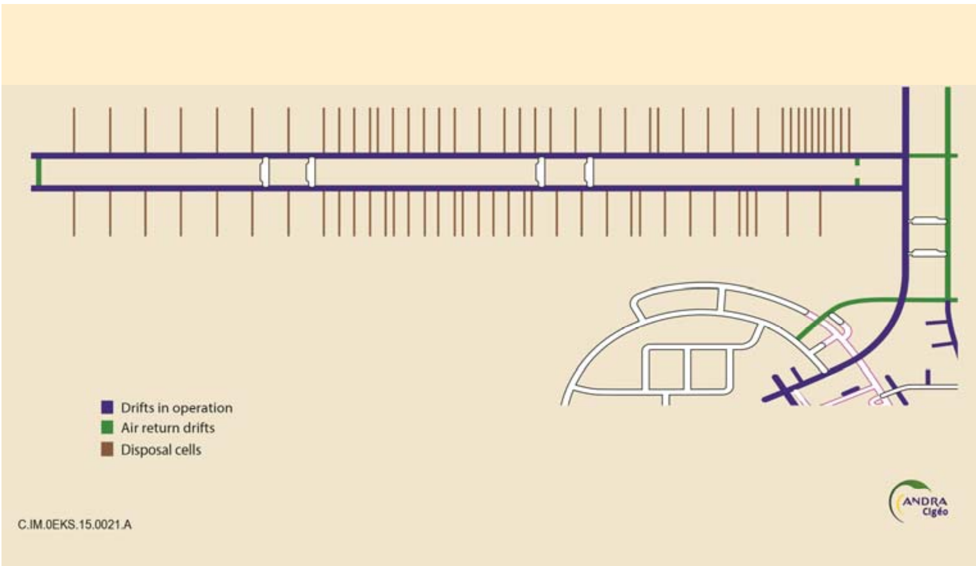


Figure 3.5-49 HLW0 disposal section (illustration at basic engineering design stage)

The HLW0 disposal section comprises the following structures:

- operating connecting drift;
- construction connecting drift;
- evacuation/emergency connecting drift;
- access drifts;
- disposal cells;
- cross cuts:

- ✓ evacuation/emergency cross cuts between access drifts;
- ✓ evacuation/rescue cross cuts between connecting drifts;
- ✓ construction/operating.

- evacuation/emergency niches (partitioning).

After closing the HLW disposal cells, the disposal section is closed (4 level of closure) by backfilling all access and connecting drifts (and cross cuts). Sealing structures in the connecting drifts complete the closing measures. The reference solution is the closure of the disposal section when the HLW section is full.

3.5.10.4 HLW1/HLW2 repository zone

The highly exothermic HLW1/HLW2 waste package repository zone is divided into disposal sections. The disposal sections comprise access drifts and HLW1/HLW2 waste package disposal cells. The disposal cells consist of modules designed to suit each thermal output class.

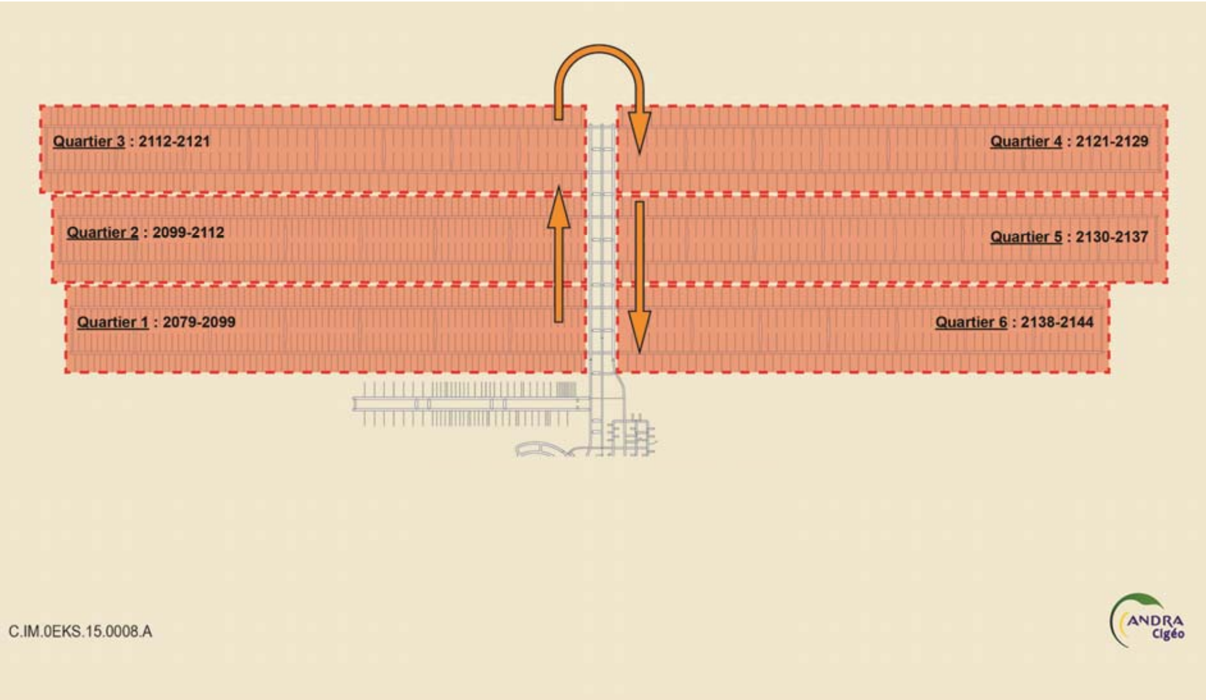


Figure 3.5-50 Principle of deployment of HLW1/HLW2 disposal sections

Deployment is managed by disposal section to maintain the physical separation between the construction and operating zones. Each disposal section converts in turn from a construction phase to an operating phase. The 1st to the 3rd disposal section are deployed using the “advancing” method, the “retreating” method is then used for the 4th to the 6th disposal section. These operations are carried out using a network of three drifts: 2 operating/construction drifts and one central evacuation/emergency drift.

The HLW1/HLW2 disposal sections comprise the following structures (see figure below):

- operating connecting drift (1);
- construction connecting drift (2);
- evacuation/emergency connecting drift (3);
- operating cross cuts between connecting drifts (4);
- access drifts (5);
- disposal cells (6);
- evacuation/emergency-LTE CFO/CFI cross cuts between access drifts (7);
- evacuation/emergency cross cut between access drifts (end of disposal section);
- evacuation/rescue-LTE CFO/CFI cross cuts between connecting drifts (8);

- evacuation/rescue niches (partitioning).

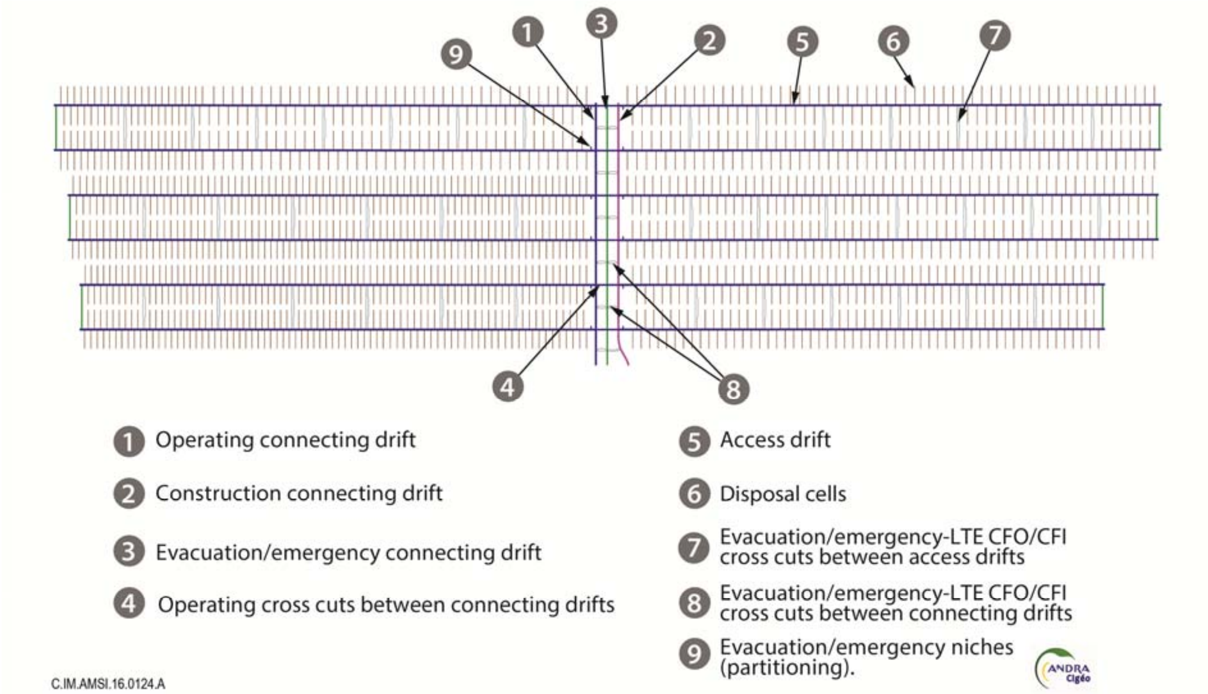


Figure 3.5-51 Top view of the HLW1/HLW2 repository zone

3.5.10.5 Design optimisation of the design of HLW repository zones and disposal cells

- THM (Thermo-Hydro-Mechanical) design optimisation and verification of failure criteria;

Based on the current state of knowledge, failure criteria with conservative thresholds (Rt = 0) are used, based on models.

Studies, model simulations, experimentation and theoretical and numerical development are being undertaken to evaluate the failure and damage conditions. The option is retained to re-inject input data during the course of the detailed design depending on the results of technical and economic studies and optimisations, in order to obtain an optimised architecture at completion which would serve as a reference for the construction licence application.

- HLW disposal cell optimisation,

Length: the reference length of 80 m for HLW0 is based on feedback from the Underground Research Laboratory and the test programme between now and the construction licence application. The reference length of 100 m for HLW1/HLW2 is liable to change due to the optimisation programme aimed at obtaining longer disposal cells (150 m).

Alternative solutions: Alternative solutions for HLW disposal cells will be studied (after the construction licence application) based on a design with non-metallic components or with provisions for limiting corrosion.

3.5.11 Transfer and disposal in the HLW disposal cells

The disposal cells comprise:

- a cask docking zone that performs a radiation shielding role;
- a cask docking facade in front of which the HLW shuttle positions the cask;
- a disposal cell head;
- a useful area corresponding to a circular metal sleeve (HLW package repository zone).

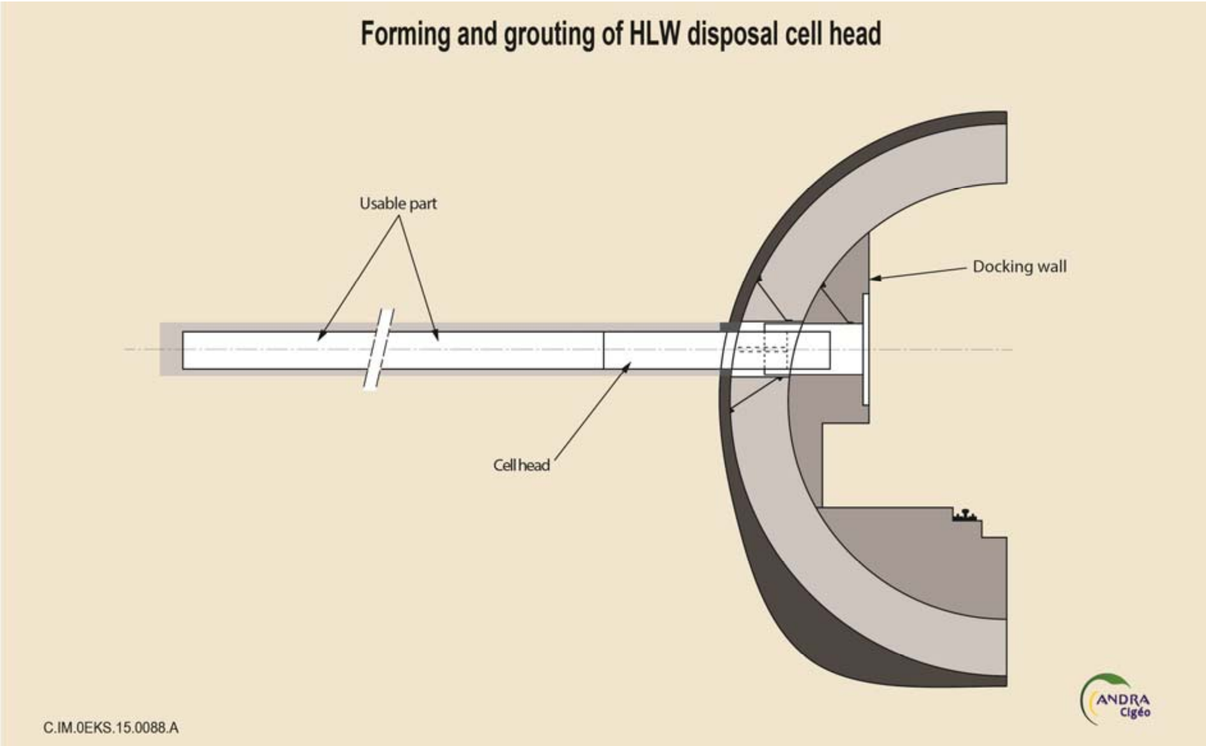


Figure 3.5-52 HLW disposal cells

An operating plug at the head of the disposal cell provides radiation shielding when packages are not being handled. For radiation protection reasons, the diameter of this plug is greater than that of the disposal cell. This plug can be removed or fitted by the HLW cask, as well as by pusher or puller robots.

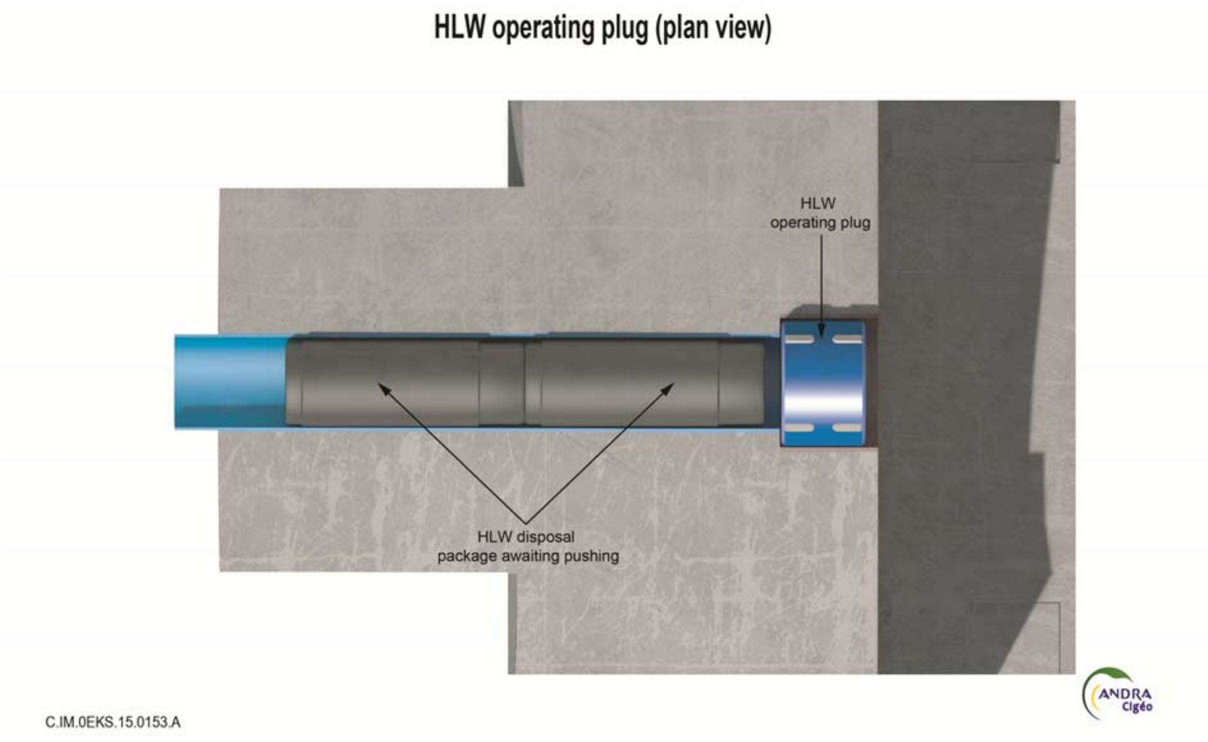


Figure 3.5-53 HLW disposal cell operating plug

The HLW disposal packages are deposited at the head of the cell by the transfer cask, then pushed to the back of the disposal cell by their pusher robot. Each pusher robot is mounted on a special cask. It travels in the access drift on a robot-specific HLW shuttle. The transfer casks and those of the pusher robots are able to remove and refit the operating plug.

The operations for the emplacement of HLW disposal packages in the disposal cells are as follows:

- docking of HLW cask;
- removal of operating plug;
- placing of HLW disposal package in the cell head;
- refitting of operating plug;
- docking of pusher robot cask;
- removal of operating plug;
- transfer of HLW disposal package (one disposal package at a time) to the end of the disposal cell by the pusher robot;
- Refitting of operating plug.

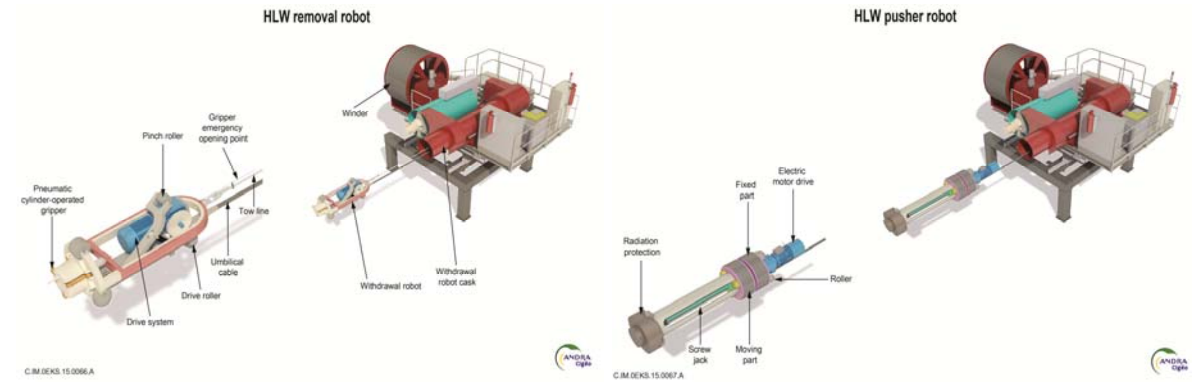


Figure 3.5-54 Cask / removal and pusher robot

3.5.11.1 General principles of operation of the HLW repository zones

The operation of the underground facility is carried out as follows:

- In the lower station and logistics support zone:
  - ✓ pick-up of full cask from the ramp transfer system by the underground cart;
  - ✓ turning of cart on the logistics support zone turntables;
  - ✓ transfer of cart with full cask to the connecting drift leading to the destination disposal section of the package.
- Within the HLW disposal section:
  - ✓ setting-down of cask opposite the access drift of the destination disposal cell;
  - ✓ turning of rail turntable;
  - ✓ pick-up of HLW cask by the HLW shuttle;
  - ✓ setting-down of HLW cask in front of the facade of the destination disposal cell;
  - ✓ docking of HLW cask with the docking facade;
  - ✓ removal of operating plug by the HLW cask;
  - ✓ placing HLW disposal package at the start of the HLW disposal cell by the HLW cask;
  - ✓ refitting of operating plug by the HLW cask;
  - ✓ removal of empty cask;
  - ✓ moving into position of pusher-robot cask by a HLW shuttle;
  - ✓ docking of pusher robot cask with the docking facade;
  - ✓ removal of operating plug by the pusher robot cask;
  - ✓ emplacement of HLW disposal package in the HLW disposal cell by the pusher robot;
  - ✓ refitting of operating plug by the pusher robot cask,

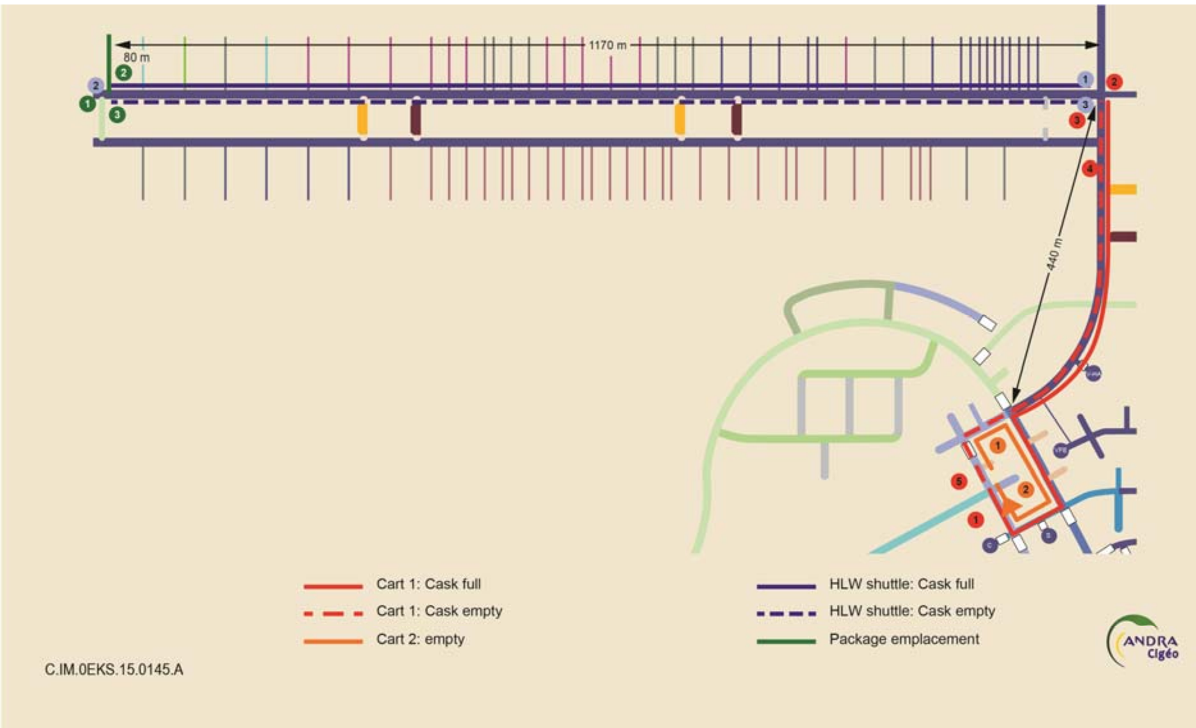


Figure 3.5-55 Diagram of the HLW0 underground transfer cycle

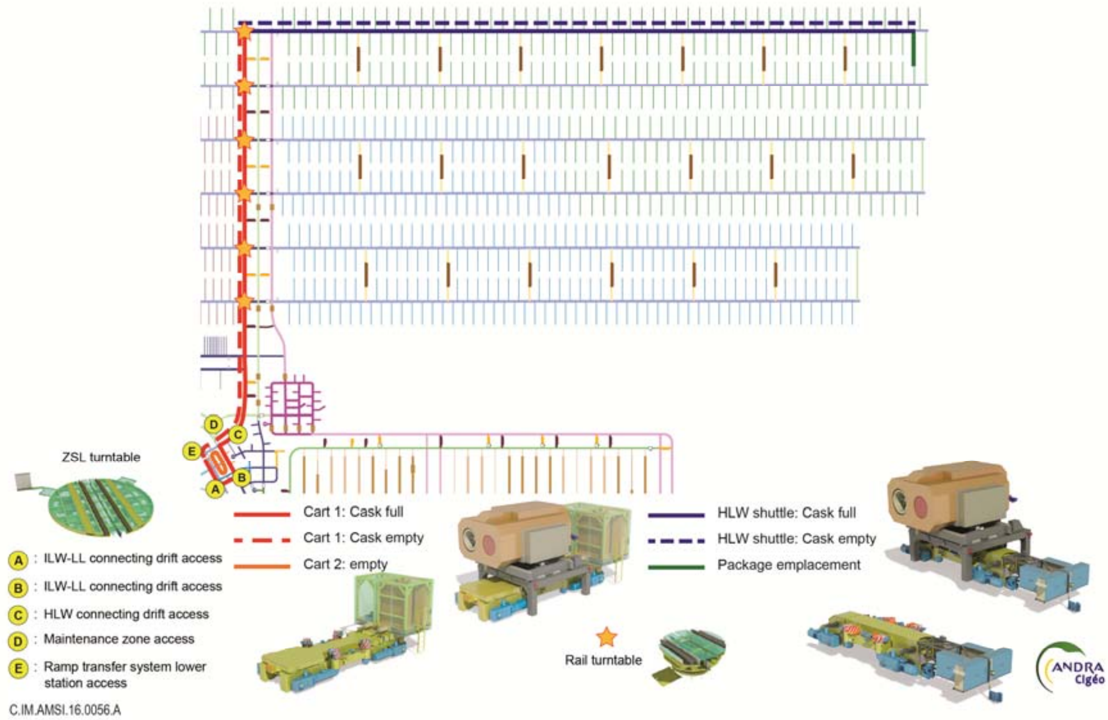


Figure 3.5-56 Diagram of the HLW1/HLW2 underground transfer cycle

3.5.12 Industrial pilot phase, test structures, demonstrators and reference disposal cells, reconnaissance and acceptance of structures

3.5.12.1 Industrial pilot phase

The objectives of the industrial pilot phase announced by Andra (board resolution of 5 May 2014) relate to:

- risk management under operating conditions;
- industrial equipment performance;
- the ability to retrieve waste packages from their disposal cell;
- the ability to monitor disposal structures;
- the ability to seal disposal cells and drifts;
- tests of possible technical and economic optimisation options.

This industrial pilot phase is planned at Cigeo's operational start-up before transition to routine operation. In particular, it will include tests to confirm, under real conditions, the ability to remove waste packages emplaced in Cigeo;

3.5.12.2 Test structures, demonstrators, reference disposal cells

Test structures and demonstrators are housed in a zone which is separated from the ILW-LL and HLW0 disposal sections containing the radioactive waste packages. "Inactive" characterisations and tests (i.e. without the presence of radioactive waste) will be performed in this zone.

- where the ILW-LL disposal cells are concerned, the implementation procedures will be confirmed prior to the construction of disposal cells within the ILW-LL disposal section;
- one or more inactive HLW disposal cell demonstrators may be constructed according to the results of the tests performed beforehand in the Underground Research Laboratory to finalise the design prior to constructing the first HLW0 disposal cells;
- certain performances of industrial equipment will be verified;
- demonstrators of representative seals will be produced. They are intended to monitor resaturation and hydraulic loading during the repository operating period over the medium term and at a representative scale: surface-to-bottom connection seal, drift seal and hydraulic cut-off;
- Studies of optimisation options will be undertaken. In particular, a large diameter ILW-LL disposal cell will be constructed on which measurements and tests will be performed prior to implementation in the ILW-LL repository zone.

These demonstrators, which will be monitored, will then become inactive reference structures.

Reference HLW or ILW-LL disposal cells, representative of a type of disposal cell, located in a repository zone or disposal section, will be monitored.

3.5.12.3 Reconnaissance, acceptance and start of monitoring of underground structures

Monitoring and data acquisition will be undertaken during excavation of the structures in order to validate the geometric geological model and its supporting physical-chemical parameters.

The current 3D geological model has reached a high technology readiness level and a high level of accuracy. Additional exploratory boreholes are scheduled to be carried out prior to constructing the surface-to-bottom connections, in particular to accurately set the depth of the surfaces of the different units on the site.

On-going geological reconnaissance will be conducted throughout the construction of the underground facility. This will serve in particular to check the homogeneity of the layer and to measure the parameters that are important for the safety functions and those that affect the sizing of the structures.

The verification of the important characteristics of the host rock, taken as input data for the assessment of post-closure safety (mechanical behaviour, extension, structure, permeability of the damaged area around the structures, etc.) forms part of the monitoring programme conducted at the start of construction of the structures, during the industrial pilot phase (and continued beyond).

As part of the monitoring programme[50], special monitoring measurements will be taken on parts of the underground structures, (stretches of ramp and of shafts, stretches of drifts or parts of intersections, of HLW and ILW-LL disposal cells), chosen as being representative of a series of structures, or because of their particular location (e.g. at the position of a future seal) in respect of the operating or post-closure safety objectives. These structures are known as “reference” structures. The specific information obtained from these “reference” structures will be integrated and implemented within the Cigeo monitoring programme. Their roles and the function of the special measurements they provide will be defined in the construction licence application.

The operational means implemented will be defined in the detailed engineering design. They will be based on feedback from the Underground Research Laboratory. These means may in particular include visual observations, cuttings, plurimetric core drilling, borehole instrumentation and non-intrusive geophysical methods.

By way of illustration, associated with the connecting drifts excavated with a tunnel boring machine, the following operational provisions can be envisaged for on-going monitoring, the installation of monitoring instrumentation, characterisation measurements and the acceptance of the works. They are specified in the detailed engineering design:

- cuttings analysis to monitor the continuity of the supporting physical-chemical parameters for safety and design;
- installation of hydro-geo-mechanical measuring equipment set back from the working face (core drilling with extensometer readings, interstitial pressure, temperature, etc.), characterisation of the excavation damaged zone (EDZ), then records of measurements as part of monitoring process (including regular convergence measurements);
- installation of instrumentation (load measurement, vibrating wire sensors, etc.) to characterise the take-up of loads, in the liner concrete, in the filling materials (e.g. compressible material) and the rock;
- geophysical measurements (seismic tomography) to characterise the EDZ (initial then record of readings as part of the monitoring process);
- Measurements of permeability to gas and water in the EDZ in the medium-term;
- acceptance of works (civil engineering, depth of EDZ, etc.) as built in compliance with the specification;
- continued records of measurements as part of the monitoring process.

Within the repository zones, according to the geometric configurations of drifts and the knowledge acquired during excavation (in conjunction with the knowledge provided by the geological model), it may be envisaged to supplement the geological model by means of core drilling or seismic tomography between drifts, prior to excavating the disposal cells.

Monitoring begins from the excavation and construction of the structures and continues throughout its operation. It consists of systematic continuous or periodic measurements of a certain number of values to check operation of the facility.

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[50] The main expectations regarding the monitoring of the underground facility are indicated in the Safety Guide: “Over and above its contribution to the safety of the facility during the operating phase, the purpose of the monitoring programme is to track the evolution of certain parameters characterising the state of the components of the disposal facility and the geological medium, as well as the main phenomena responsible for such an evolution. The monitoring programme based on the updating of scientific knowledge must be able to show that the above-mentioned phenomena have been correctly anticipated and remain under control. It also provides the elements necessary for the management, operation and reversibility of the facility. The means used for monitoring must not reduce the safety of the repository”. The guide also indicates: “A monitoring programme of the facility must be implemented during the construction of the disposal structures and continue until the closure of the facility. Certain monitoring measures may also be maintained after the closure of the facility”. Regarding post-closure monitoring, the guide states: “the protection of human health and the environment must not depend on monitoring and institutional checks which cannot be maintained with certainty beyond a limited period".

3.5.13 Underground facility auxiliary systems

[Note to reader: the auxiliary systems use many abbreviations, they are shown in bold text at the first time of use]

The architecture and the description of the high voltage range "A" system (HTA) and the communications and security systems (CFI) are part of a system architecture.

3.5.13.1 Systems (CFI)

Interlocks are implemented between:

- **the SSI (Fire control system)** and the nuclear ventilation system and its own control system, **nuclear ventilation functional unit (EF VN)**;
- the SSI and the mechanical equipment located in the **logistical support zone (ZSL)** and in the drifts (e.g. The airlock and isolating doors);
- the radiation protection system, **radiation protection functional unit (EF RP)** and the nuclear ventilation system.

Beyond the underground facility and the associated CFI systems, the ramp transfer control system and the equipment for handling the disposal package transfer casks in the logistics support zone and in the drifts, as well as the ILW-LL and HLW disposal cell emplacement equipment are impacted by information from the CFI functional units. Typically the detection of a fire, **fire control system functional unit (SSI),** will cause the activation of the previously mentioned control systems to place the equipment concerned in the fallback position or the safe shutdown state.

Information is exchanged via interoperability modules enabling the transfer of the data to be exchanged between the systems concerned (SSI, VN, RP), each with their own communication network (independent physical support).

<u>Communications and Security Systems</u>

A certain number of functional units of the Cigeo industrial information system (SII) are concerned by the activities of the nuclear process sub-systems, the underground facility and the ramp transfer.

The function of each of these units or systems is described in section1.6 of this document (Auxiliary systems of the Cigeo facility).

The functional units relating to the underground facility are as follows:

- The **DP (Special measures)** functional unit relating to access control, intrusion detection, surveillance (roundsman system) and building video-supervision;
- The **SSP (Personnel safety system) functional unit relating to the personnel safety systems** in controlled areas;
- The **VDI (Voice, Data, Image),** functional unit relating to telephone, inter phone, video broadcasting network (television, site information) radio-communication;
- The **BMS (Building Management System)**) functional unit for managing the fluids and utilities, and the LV electricity and the shaft lifts;
- The **GTC (centralised technical management system)** functional unit relating to the acquisition of critical data (alarms, events),
- The **GTE (Power Management System)** functional unit relating to the surveillance and operational maintenance of the electrical networks,
- The RP (Radiation Protection) functional unit for ambient radiological monitoring, the monitoring of gaseous and liquid discharges, the monitoring of atmospheric discharges from exhaust stacks and operational dosimetry;
- The SSI (Fire control system) functional unit for the fire detection and suppression in building EP1;
- The VN (Nuclear Ventilation) functional unit;
- The equipment **MCO (through-life support)** functional unit using the **computer-aided maintenance management (CAMM) system.**

The functional units relating to the nuclear process and ramp transfer sub-systems are:

- The GTC (centralised technical management system) functional unit, relating to the acquisition of critical data (alarms, events);
- the PMS (Power Management System) functional unit related to the surveillance and operational maintenance of the electrical systems;
- the SSI (Fire control system) functional unit for the fire detection and safety of building EP1;
- The equipment through-life support (MCO) functional unit using the computer-aided maintenance management (CAMM) system.

3.5.13.2 Ventilation

General principles

The construction and operating zones each have an independent ventilation system. This ventilation is based on a "push-pull system" consisting of an air supply system and an air removal system. This system, which is commonly used in tunnel and underground metro systems:

- controls pressure cascades between the different underground operating areas, ensuring a better distribution of air between the different sections of the facility and greater flexibility for adjusting and balancing the networks;
- Minimises air leaks between the operating zone and the surface;
- Maintains minimum ventilation in the event of the loss of one of the two ventilation plants, while maintaining air flow direction;
- Distributes the head losses experienced by the fans between the 2 plants, and thus maintains the ventilation equipment within the suppliers' 'standard' ranges. In the case of a design using a single ventilation plant, the pressure on the fans would be of the order of 10 kPa or more, requiring "customised" equipment resulting in higher investment, maintenance and renewal costs. The operating costs are therefore reduced.

The operating zone is ventilated via two shafts and the two ramps: fresh air is supplied via the operating personnel shaft and is returned via the operating air return shaft and via the package and service ramps.

The construction zone is ventilated via the construction personnel shaft and the construction air return shaft: fresh air is supplied via the construction personnel shaft and returned via the construction air return shaft. It is important to emphasise that a non-significant flow (relative to the overall need for that zone) circulates in the equipment and construction shaft (this flow is not shown in the associated figure).

Ventilation of the operating zone

Fresh air is supplied to the operating zone via the operating personnel shaft. A plenum at the level of the shaft distributes the air to the different underground zones: ILW-LL, HLW/HLW0 and the operating logistics support zone.

- ILW-LL zone

The ILW-LL zone is supplied via the plenum. Fresh air circulates in the full section of the ILW-LL connecting drifts then passes via the access drift in order to pass through each disposal cell of the zone. The stale air (from the disposal cell) is removed after HEPA filtration through a dedicated duct within the air return drift and arrives at the operating air return shaft. This air is finally exhausted to the outside.

- HLW/HLW0 zone

The HLW/HLW0 zones are supplied via the plenum. The fresh air circulates in the full section of the HLW (or HLW0) connecting drifts then crosses the two disposal cell access drifts of the HLW (or HLW0) disposal section during the package filling phase. A vent at the end of each access drift removes the (stale) air crossing through this drift to the operating air return shaft. This removal is done via a flue in the upper part of the access and connecting drifts. This air is then discharged towards the outside via the operating air return shaft.

- Logistics support zone (ZSL)

The logistics support zone is supplied via the plenum. Fresh air circulates in the full section of the drifts forming the zone. Vents located at the ends of certain drifts within this zone remove part of the air from this zone, the other part of this air serving to supply air to the two ramps. The extracted air is then directed towards the operating air return shaft via a flue located in the upper part of the drifts. This air is finally discharged to the outside.

- Ramps

The two ramps are supplied with air taken from the operating logistical support zone. The air circulates in the full section of the two ramps before being exhausted to the outside.

Ventilation of the construction zone

Fresh air is supplied to the construction zone via the construction personnel shaft. This is a “blown-air” type ventilation system. The fresh air from the construction personnel shaft circulates in the ventilation pipes located within the upper part of the construction connecting drifts to supply clean air to working face. The air is removed in the full drift section after treatment by dust collectors situated in the duct close to the working face. This air circulates in the connecting drifts towards the construction air return shaft before being exhausted to the outside.

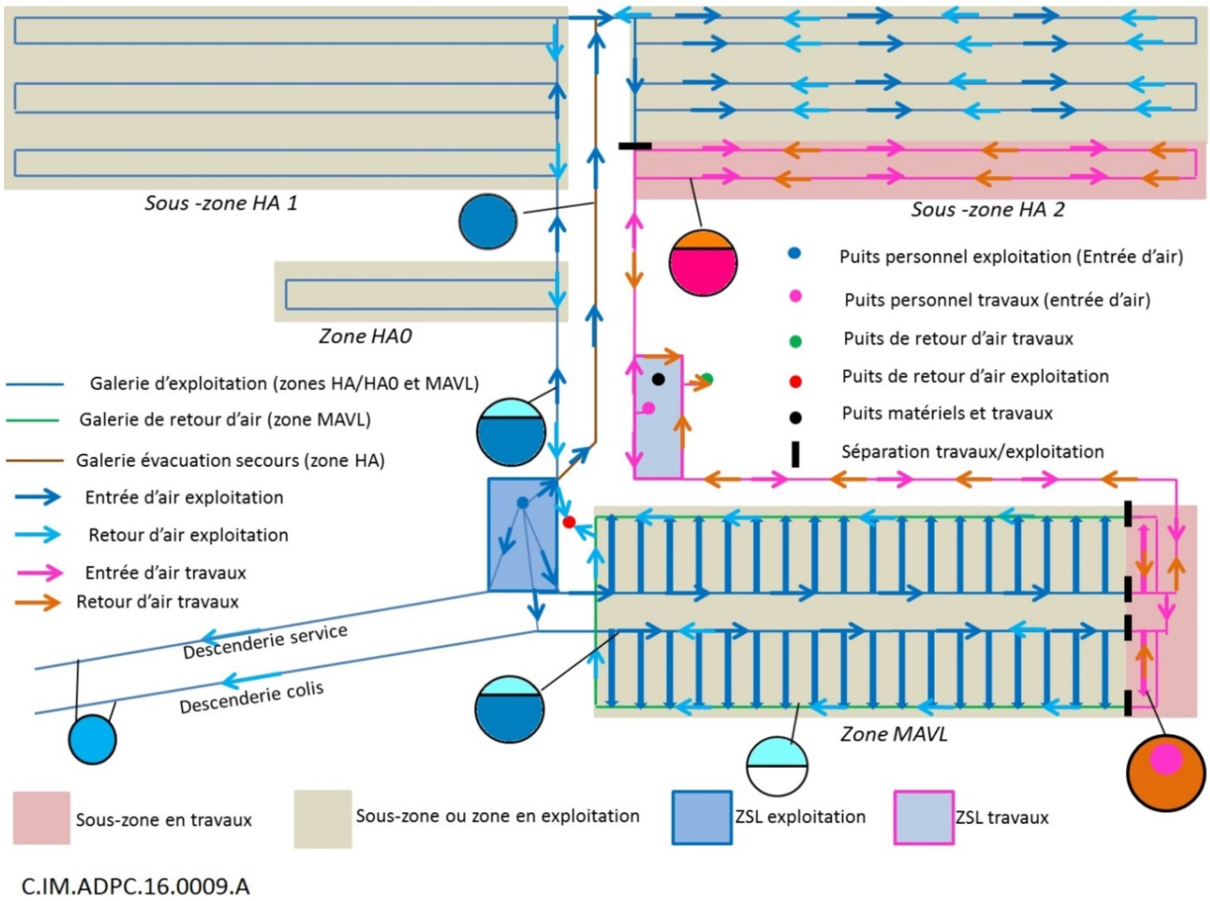

Figure 3.5-57 Diagram of ventilation system operation (timeless)

3.6 Auxiliary systems of the Cigeo facility

3.6.1 Industrial information system

The general functional architecture of the Cigeo industrial information system (SII) is broken down as shown in the following diagram:

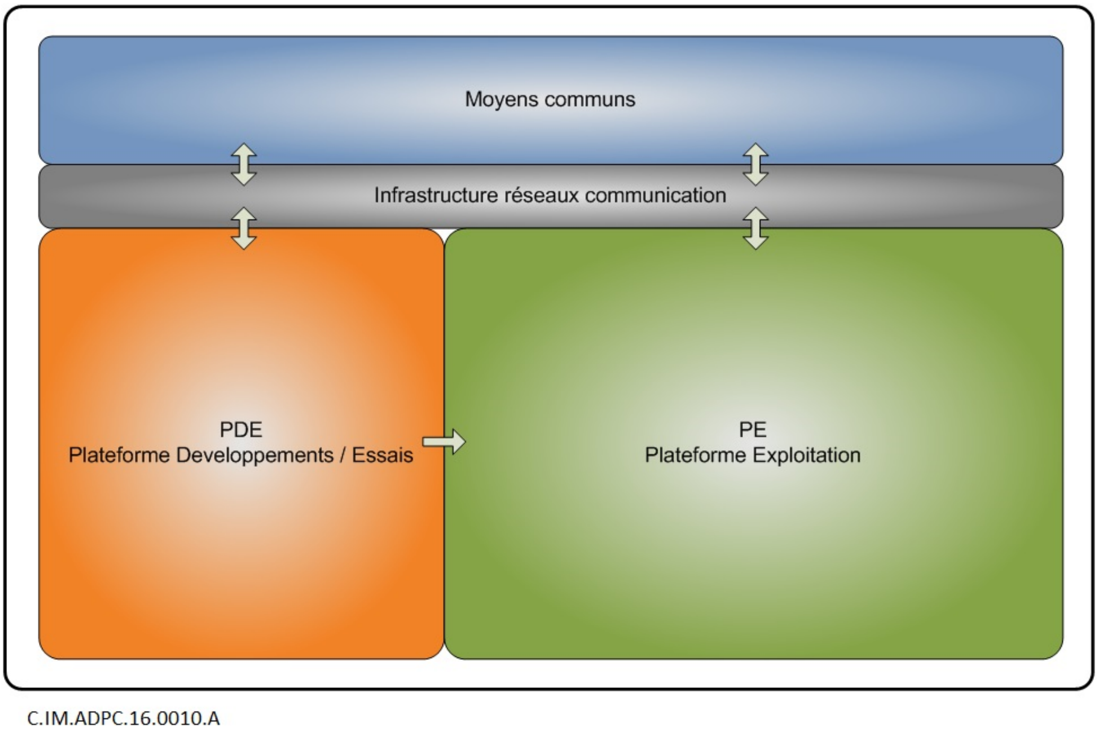

Figure 3.6-1 General functional architecture of the Industrial information system (SII)

Two cross-functional units the “common resources” and the “communication network infrastructure” systems contribute to the functioning of two operational platforms:

- the Operating platform;
- the Development/Testing platform.

The term “platform” covers all the operational means applied to the development, testing and operating activities. It includes:

- the rooms within which the development, testing and operating activities of the site are conducted,
- the means of communication and instrumentation and control,
- the field equipment and devices.

The Development/Test platform represents the means and functions necessary, during the period of coordinated working, for the development, testing and integration activities, as well as for training activities.

The Development/Testing platform can be used to test and qualify the gradual extensions (hardware, applications, etc.) prior to roll-out on the operating platform.

Its structure, which is of a significantly identical configuration to that of the operating platform, ensures that it can serve to:

- validate the tests conducted under conditions close normal operation;

- train and upgrade the skills of control operators via simulation software of the operating part.

This platform is based on the common resources of the industrial information system.

The common resources provide all the computer operating and maintenance needs of the industrial information system.

The communication network infrastructure forms the physical and logical links between equipment and software.

The physical medium of the main industrial information system network consists of single-mode multistrand fibre optic cables suitable for the applications:

- Having a riser-installed backbone type business communication infrastructure with horizontally routed feeder cables;
- Capable of supporting all computer network applications such as VDI, FDDI, Gigabit Ethernet;
- Fire resistant, zero halogen, sealed cables suitable for internal and external use;
- With an expected service life > 60 years
- Resistant to the local radiation levels.

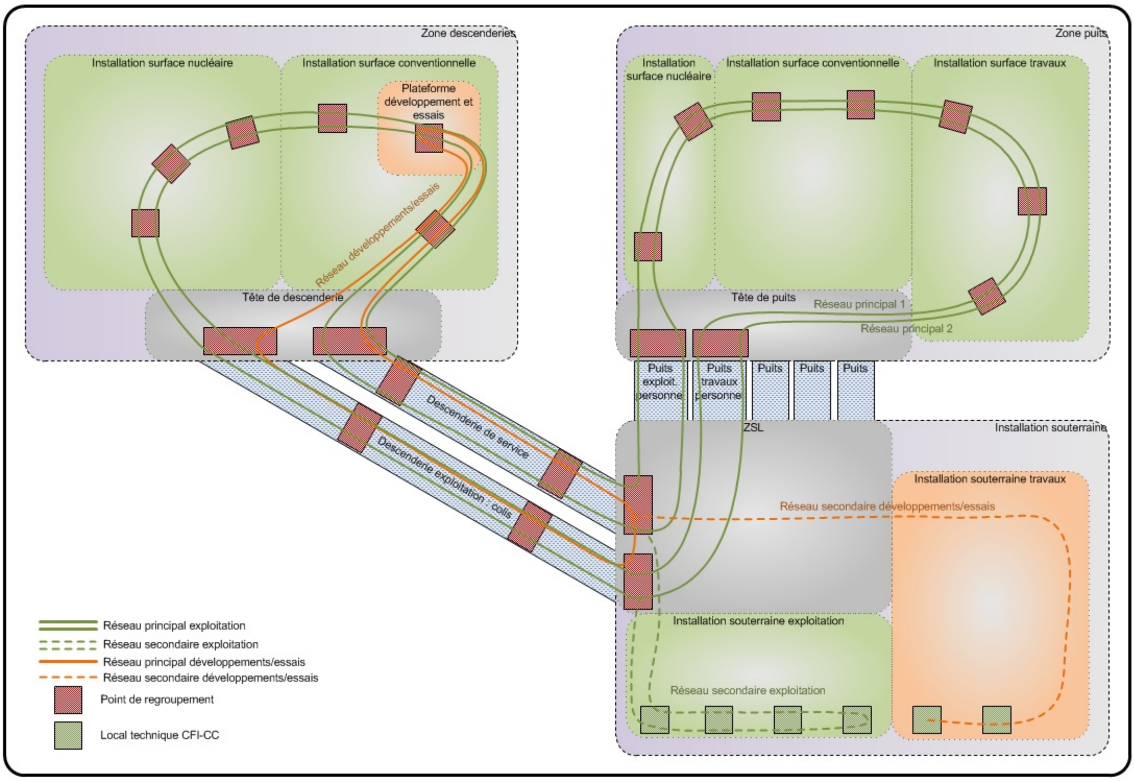

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Figure 3.6-2 Communication network infrastructure

The 2 self-healing rings using a HSR standard secure protocol for high-availability networks.

All data are duplicated via two resilient high-speed network rings using the HSR/PRP protocol.

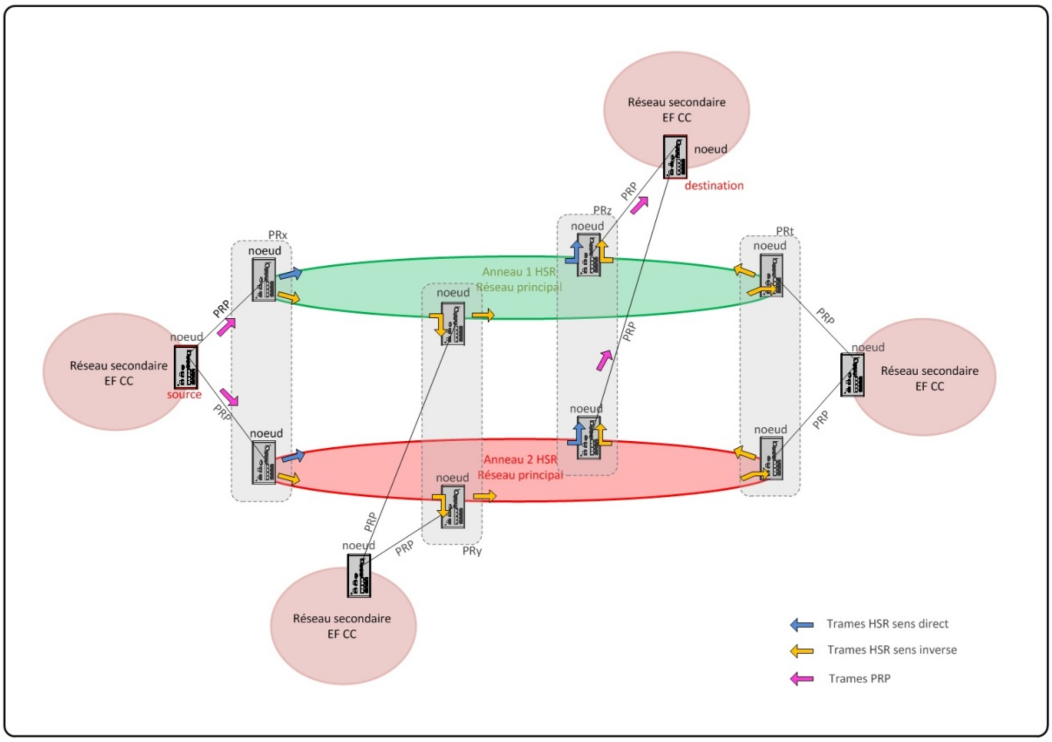

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Figure 3.6-3 General network architecture principle for a functional unit including secondary network connections

The main operating network covers all the communication requirements of each functional unit and covers all the operating areas.

For requirements linked to the availability and operating safety of the instrumentation and control system, the means of communication are redundant.

The industrial information system is organised into 15 functional units (EF) which correspond to the communications and security systems (CFI) and the nuclear process instrumentation and control system which will be implemented:

- ADM: ADMinistration;
- CC: Nuclear process instrumentation and control system
- GMN: Management of nuclear materials;
- DP: Special measures;
- SSP: Personnel safety system;
- VDI: Voice, Data, Images;
- BMS: Building Management System;
- GTC: Centralised technical management system;
- GTE: Power Management System;
- RP: Radiation Protection;
- SSI: Fire control system;
- VN: Nuclear Ventilation;
- OS: Observation monitoring;
- SE: Environmental monitoring
- MCO: Through-life support

A diagrammatic representation of the organisation of Cigeo into functional units is shown below.

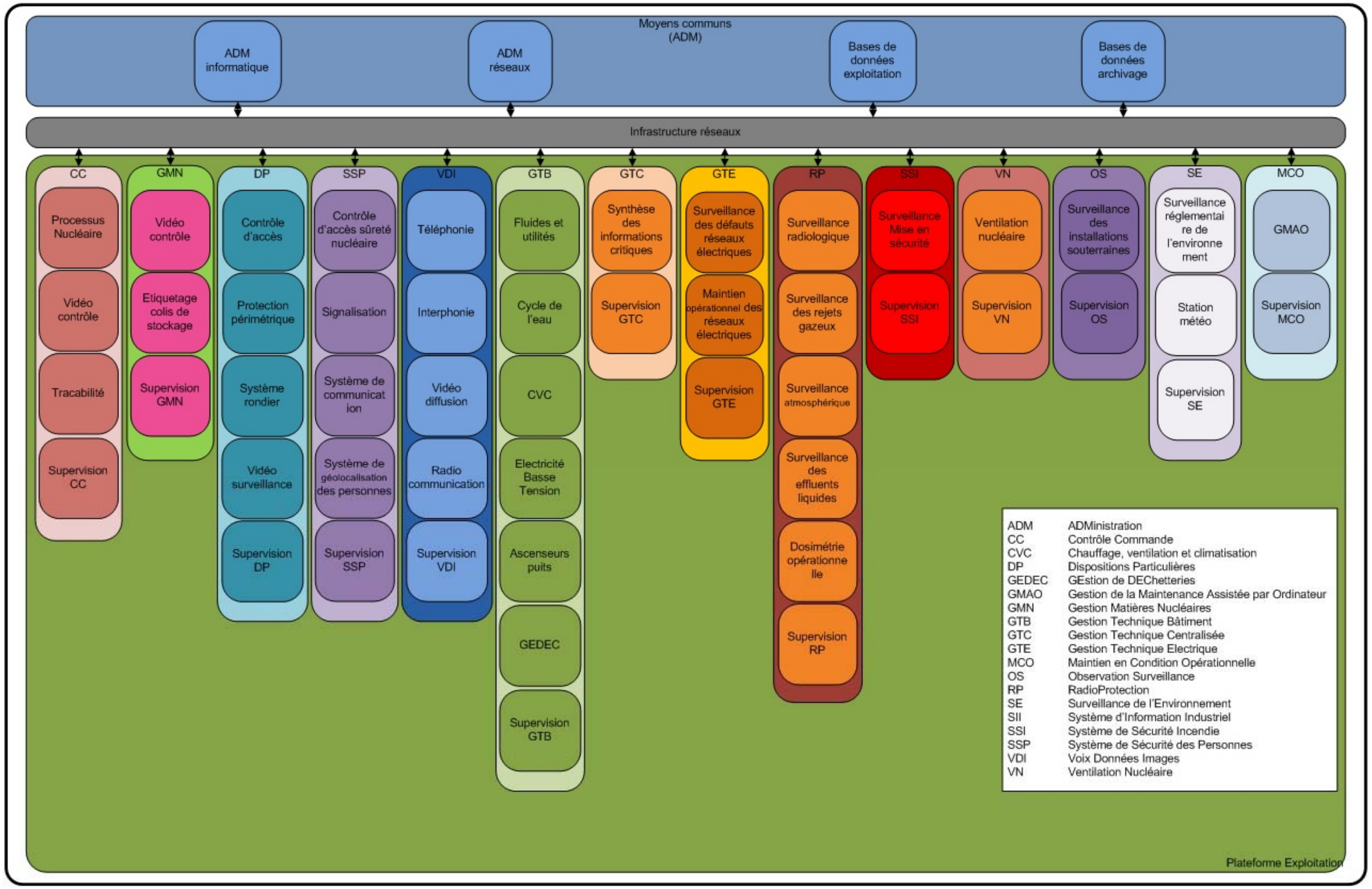

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Figure 3.6-4 *Diagrammatic representation of the organisation of Cigeo into functional units*

The structure of the main network adopts a physically independent distribution to each functional unit to guarantee that functional domains are sealed from one another. Grouping of functional units may be envisaged if necessary to share the means of communication between functional units.

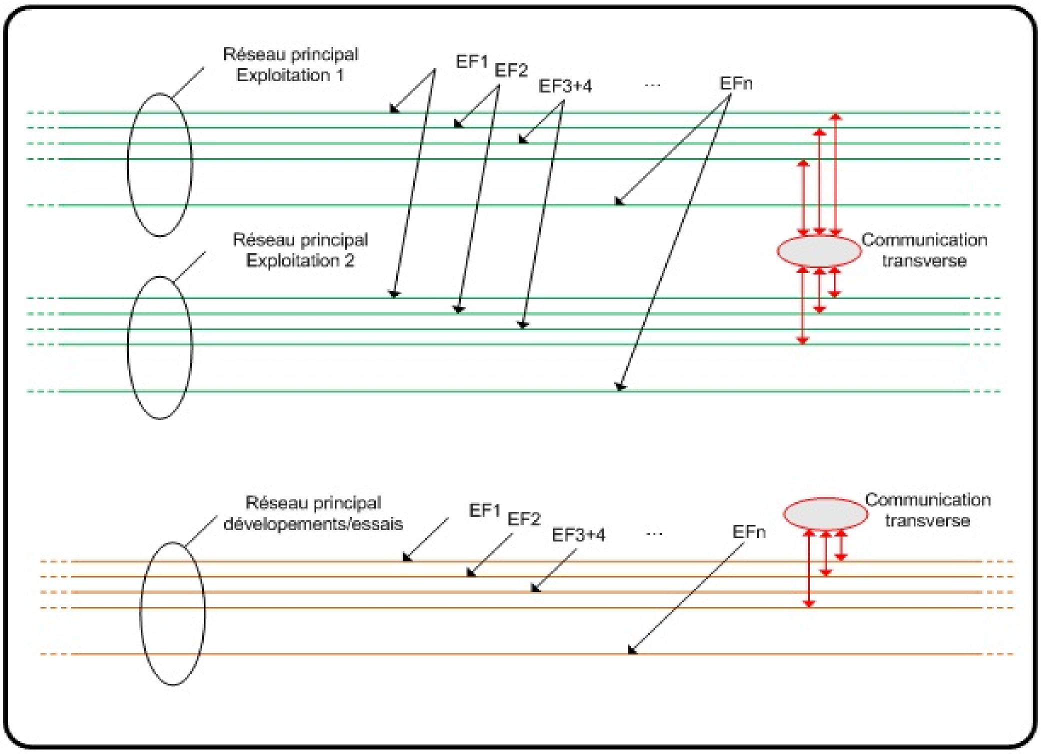

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Figure 3.6-5 Main network distribution principle

For cross-communication between functional units, an application interoperability module is set up to allow communication between different domains while guaranteeing the principle of independence of networks by functional unit.

This principle of distribution is also applied to the dedicated development/testing platform communication network.

Distant pathways are planned to separate, as far as possible, the outward and return paths of the ring on the one hand and the redundant network on the other.

The overall network architecture and data acquisition and processing levels according to the CIM concept are shown below.

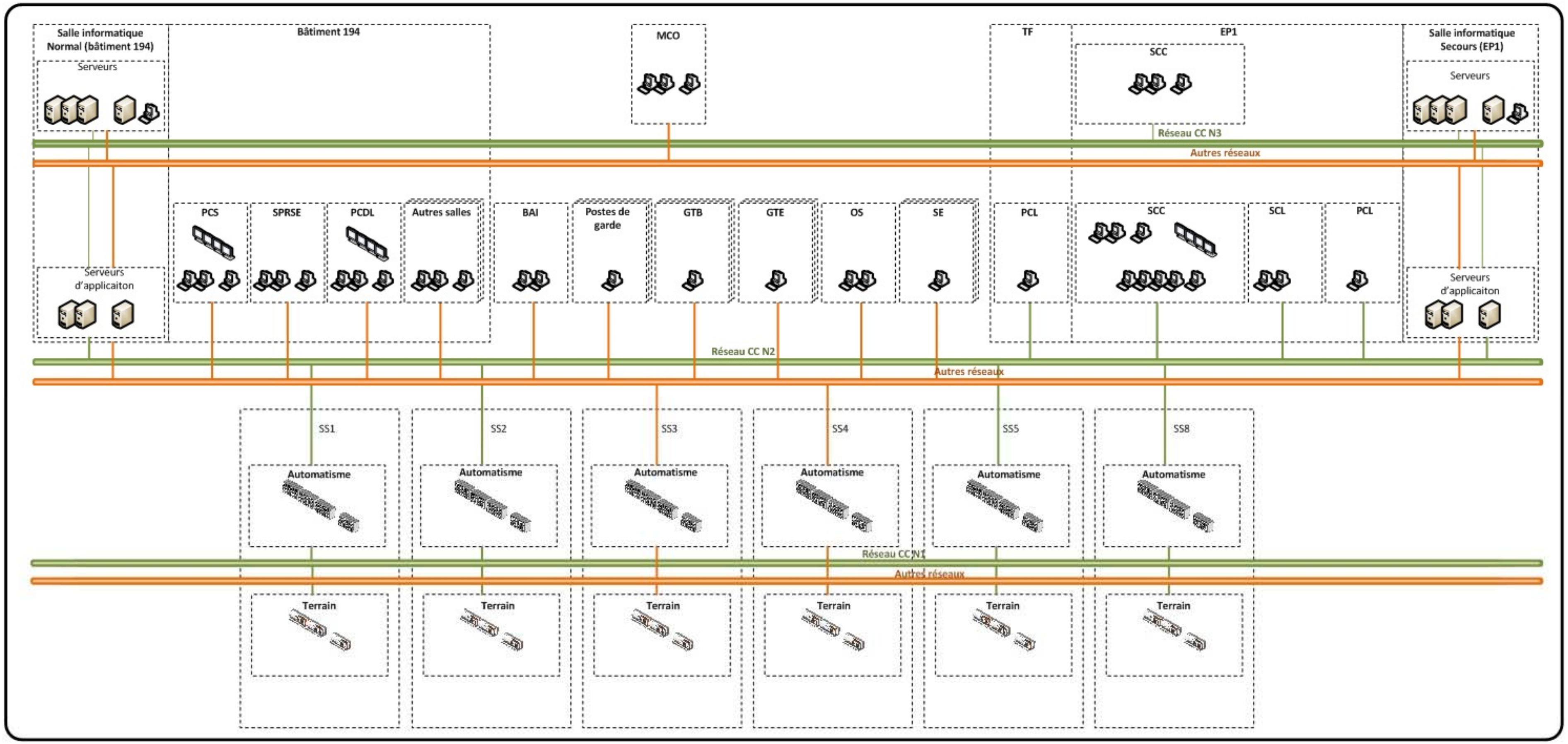

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Figure 3.6-6 Overall network and data acquisition and processing level architecture

3.6.2 Communications and Security Systems

The Communications and Security Systems correspond to the following 14 functional units:

- ADM (ADMinistration): groups together the common resources of the office automation level data processing systems;
- GMN (Management of nuclear materials): the operation of a basic nuclear installation requires the implementation of an accounting and control system for the nuclear material present within the installation. This system keeps an account of the material held within Cigeo in accordance with the Euratom requirements;
- DP(Special measures): serving the local safety and security team (FLS) at the security control centre (PCS). It provides the means for controlling access and protecting people and property against malicious acts, sabotage or terrorism via a centralised supervision system. It comprises four functional systems or sub-units:
  - ✓ access control;
  - ✓ roundsman system;
  - ✓ perimeter protection;
  - ✓ video surveillance.
- SSP (Personnel protection system): it controls the engineered safeguard systems and devices involved in ensuring the protection of personnel within controlled areas through a centralised supervision system. The SSP comprises a number of devices for ensuring the application of the safety rules. It monitors and controls the controlled area access safety devices, informs and tracks individuals on the site via four functional systems or sub-units:
  - ✓ nuclear safety access control;
  - ✓ signalling;
  - ✓ communication, including site public announcement system and site warning siren activation;
  - ✓ personnel geolocation;
- VDI (Voice, Data and Images): supplies the on-site means of communication though a centralised supervision system. It comprises four functional systems or sub-units:
  - ✓ telephony;
  - ✓ intercom;
  - ✓ video broadcast;
  - ✓ radio communication;
- BMS (Building Management System)): provides the means necessary for managing the buildings' mechanical and electrical equipment such as heating, ventilation and air-conditioning (HVAC) and electricity (building and site lighting) through a centralised supervision system. The shaft zone lifts, the water treatment stations, as well as the site waste collection centres are also monitored and controlled by the BMS. The BMS functional unit incorporates six main functional systems or sub-units:
  - ✓ Control and management of fluids and utilities. The cold production process forms part of the "fluids and utilities" functional sub-unit;
  - ✓ Water cycle;
  - ✓ Building heating, ventilation and air-conditioning (HVAC);
  - ✓ LV electricity (lighting, low power circuits, PC distribution, etc.);
  - ✓ Shaft lift control (Shaft lifts);
  - ✓ Conventional waste management and control.
- GTC (Centralised technical management system): provides the means necessary for acquiring and synthesising critical information from the site and the other functional units through a centralised supervision system chiefly located in the security control centre (PCS).. The GTC functional unit incorporates the "Synthesis of site faults and alarms" sub-unit.
- GTE (Power Management System): oversees the operation of the High Voltage range "A" and range "B" and low voltage power systems by performing monitoring, control and automation. Ensures continuity of activity and guarantees the reliability and availability of the site's electrical installation through centralised supervision for piloting the electrical installation, the monitoring and the control of the networks and automatic reconfiguration of the power supply systems. The GTE

functional unit comprises two systems: “electrical system fault monitoring” and “electrical system operational continuity”. The electrical systems covered by this functional unit are the High Voltage range “A” and range “B” and low voltage systems. The GTE also manages the emergency diesel generators. It generally manages all the electrical power sources and distribution systems, the delivery and distribution stations, sub-stations and electrical equipment rooms.

- RP (Radiation Protection): performs the radiological and dosimetric measurements and analyses associated with the activities of the site via a centralised supervision system or a radiation monitoring panel. The RP functional unit comprises five functional systems or sub-units:
  - ✓ radiological monitoring of the nuclear zones of the site;
  - ✓ radiological monitoring of gaseous discharges;
  - ✓ radiological monitoring of atmospheric discharges;
  - ✓ radiological monitoring of liquid effluents;
  - ✓ dosimetry.
- SSI (Fire control system): it performs fire protection and monitoring of the site by means of self-contained field devices and a centralised monitoring system located in the security control centre (PCS). The overall fire control system covers all Cigeo surface and underground facilities. It performs fire detection and the fire suppression actions necessary for ensuring the safety of the facilities and people. Fire suppression scenarios are coordinated with the nuclear ventilation instrumentation and control system (EF VN) and the nuclear process instrumentation and control system (EF CC). The SSI functional unit incorporates the “fire monitoring and suppression” functional sub-unit. Fire suppression is performed either by fire suppression control units (CMSI) attached to a fire control system (SSI), or by programmable logic controllers (PLCs) if the suppression operations are too complex to be performed from a CMSI ;
- VN (Nuclear ventilation): monitors and operates the ventilation system in the nuclear activity areas of the surface and underground facilities in accordance with the operational requirements of a basic nuclear installation. Safety scenarios (smoke extraction from compartmentalised areas) performed by the PLCs are coordinated with the fire control system (SSI). The PLCs also manage the rebalancing of the ventilation networks in the event of disturbance due to the running of a smoke extraction scenario. The VN functional unit incorporates the nuclear ventilation control and regulation system. Nuclear equipment is supervised from the centralised control room. If necessary, remote control actions may be performed from the centralised control room or locally from the HMIs on the front of the ventilation instrumentation and control cabinets;
- OS (Observation monitoring): Acquisition and monitoring of the measurements required for detecting changes in the underground structures, including the operating ramp. The OS functional unit incorporates the observation and monitoring acquisition systems.
- SE (Environmental monitoring): acquires and monitors environmental measurement data during the operation of Cigeo and after its closure. It incorporates the environmental monitoring instruments and the meteorological stations
- MCO: (through-life support): handles the maintenance activities of the site. It incorporates the CAMM (Maintenance management) functional sub-unit which is fed with data enabling it to advise when corrective, preventive or predictive maintenance is required.

3.6.3 Nuclear process instrumentation and control system

3.6.3.1 Objectives of the instrumentation and control system

Main objectives

In order of priority, the control- command system will meet the following objectives:

- Nuclear/industrial safety objectives specified in the safety documents drawn up in accordance with applicable laws concerning Basic Nuclear Installations. These objectives define an initial operating range: the range specified for the security of the facility.
- Production objectives, in other words achieving the desired rate of production to the required level of product quality, on, time and at cost in application of the operating procedures and instructions. These objectives define a second operating range: the range specified for production.

The intersection of these two ranges constitutes the authorised operating range. A deviation in the production process may, depending on the consequences, cause:

- The triggering of a process alarm (of a control chart pre-alarm) warning that the process is outside the production range. There are two levels of alarm (A2 and A3 presented in Figure 1 to which are added the minor "information" level A1 alarms) according to the degree of severity or of urgency required of the operator to intervene. These events can lead to an automatic action via a programmed activation in the normal production system.
- The triggering of a safety alarm, warning that the process is outside the safety range. These events can lead to an automatic action processed by the safety system.
- The safety alarms, which are limited in number, and the corresponding safety functions will be defined in the safety documents of the facility. Within the normal operating range, there are signalling thresholds, minor level A1 alarms and operator thresholds to assist operation and anticipate deviations. These concepts are presented in the following diagram.

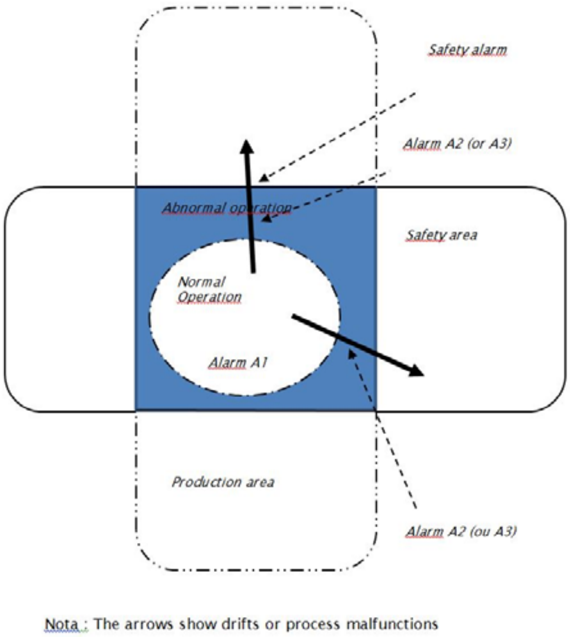

Figure 3.6-7 Diagram representing the operating ranges

<u>Other objectives</u>

The instrumentation and control system will also meet the following objectives:

- Consistency of solutions within the framework of a global approach in order, in particular, to minimise the stock of spare parts and facilitate maintenance of the facility. Generally, a single type of system should manage the entire plant. For packages, the use of specific automatic controls should be clearly justified by the technological (cycle time) or project requirements (procurement of complete packages, for example, to clearly place liability upon a supplier) or any other requirement specific to the equipment concerned. In any event, the choice of automation and operating equipment must be standardised.
- Implementation of “advanced” functions, such as:
  - ✓ Availability of maintenance information on the control station to enable a first level diagnosis on the actuators, instrumentation and the instrumentation and control system.
  - ✓ Integration within the display of contextual operator assistance (operating procedures, actions to be performed in the event of alarms (emergency instruction sheets)). This integration can only be gradually implemented after a process operation learning period.
  - ✓ Filtering of alarms for improved diagnosis of the 1st fault.
  - ✓ Remote diagnosis and centralised database of variable speed drive parameters and motor starters. Installation of a control room station.

All of these features require the installation of field networks, both for the sensors and the actuators, as the flow of data carried from level 0 to the upper levels will significantly increase (compared to a hard-wired technology).

3.6.3.2 Safety requirements applied to the instrumentation and control system

At this stage, the instrumentation and control systems consist mainly of a normal production system, a “safety” system and a “back-up” system (if necessary). The safety channels prevent and limit the consequences of feared events, whatever the anomalies of the normal control system. These channels can be either active or passive. They are classified according to the severity of the events.

The instrumentation and control channels of the normal control system are "non-safety class" as they are not subject to any nuclear safety requirements. They may, if applicable, perform functions aimed at protecting the production facility or the workers.

The safety channels, forming part of the safety or (if applicable) back-up instrumentation and control system, aim to maintain the process in a safe state regardless of the state of the installation, in the event of a malfunction on the normal control system.

The safety function instrumentation and control systems are independent from the other instrumentation and control systems. According to the requirements and/or the reliability to be achieved, the safety functions ensured by these systems may be redundant or, if necessary diversified. The data from the safety sensors required for normal operation may be sent to the normal system (PLC) via the safety instrumentation and control system. The safety system may use either hard-wired or programmed logic.

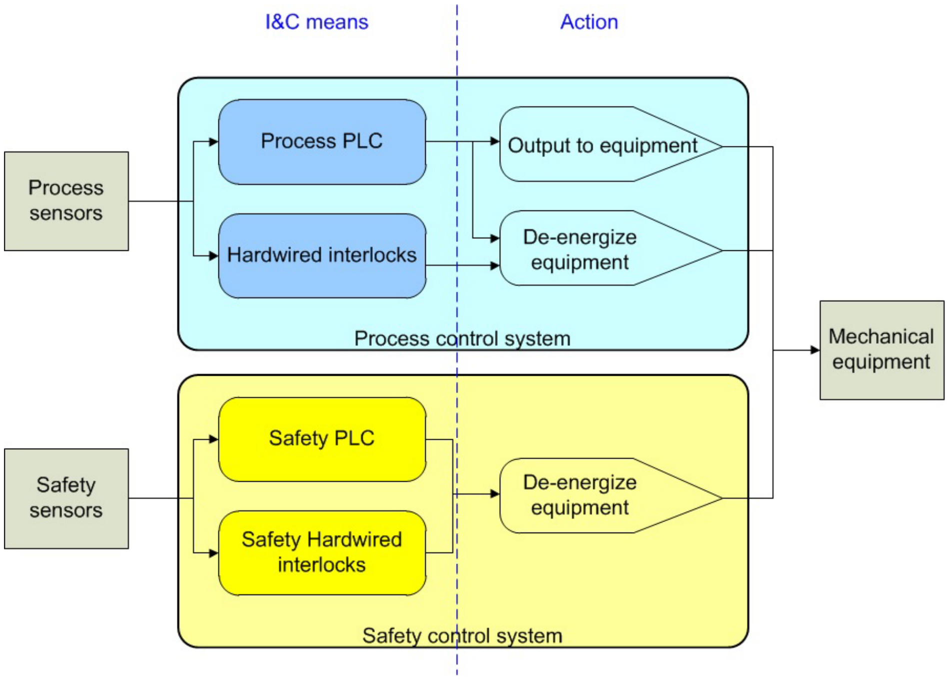

Figure 3.6-8 The different instrumentation and control systems and sensors

3.6.3.3 Description of the instrumentation and control system

<u>General</u>

The control command system serves to acquire, transmit, interpret and process data exchanged between the process and the supervision system. The use of programmed, standardised automatic controls provides users and designers with high levels of processing power and flexibility of use. This, in particular, simplifies maintainability.

The instrumentation and control system of a workshop must comply with the following guiding principles:

- the safety requirements, together with the requirements concerning personnel and the environment;
- centralised control-room based operation of the workshop's main functions;
- protection of the work equipment
- presentation of information to the operator in a non-interpretable, easy-to-use and understandable format.

Implementing these principles leads us to divide the instrumentation and control system into two (or three) sub-assemblies, which are as follows:

- The normal control system for controlling and managing production within the operating authorised range, while at the same time meeting the safety and product quality objectives. This system can also play a role in monitoring the correct operation of the components of the safety instrumentation and control system (which has its own self-check devices). The normal control system does not play any part in the safety channel. It does however improve the reliability of the overall control command system. Special Work Tool and personnel protection devices (POT), directly incorporated within the normal and emergency-supplied electrical distribution cabinets, act upon the power supply to the actuators on detection of a risk situation for the equipment, the product or the personnel. The POTs override other systems to shut-down actions in progress, except in the case of transition to post-earthquake safeguard operation when they would be disabled. The operation of these automatic controls are signalled on the monitoring equipment;

- The safety system is a system which, in the event of a production system failure will:
  - ✓ place and maintain the facility in a safe state either automatically or upon operator action;
  - ✓ check that the facility remains in the safe state.

  The safety system has the following general characteristics:
  - ✓ it controls only the safety functions;
  - ✓ it is independent of the production system;
  - ✓ it is activated in the event of partial or total failure of the production system (control station, control equipment, connections, sensors, actuators);
- The safety instrumentation and control system comprising the following two sub-systems:
  - ✓ a first sub-system comprising active safety channels to control the safety functions when the facility is in the normal state;
  - ✓ a second sub-system commonly referred to as the "safety panel" which enables emergency shutdown of the facility and, if required, plays a part in making it safe, especially in the event of partial or total failure of the normal control system (we refer in this case to a “safety control” function[51];
  - ✓ A safeguard instrumentation and control system for controlling and monitoring the safety functions required in the safeguard condition.

- **Operating mode**

The available operating modes are, as a minimum:

- automatic mode: the production cycles run without the intervention of the operator (or only a few operator validation actions from a local terminal). This is the normal operating mode;
- interlocked manual mode: following an anomaly, the operator may directly operate the actuator control to “reset” the machine and restore it to a state in which the automatic cycle can be resumed. In this mode, the programmed and hard-wired safety functions remain enabled;
- testing/maintenance manual mode: this mode is essentially used during the testing and maintenance phases. In this mode, the programmed and hard-wired safety functions are disabled The hard-wired safety functions can be disabled by the maintenance operator by means of a switch.

Each functional unit defined is independent for performing operations in manual maintenance mode from the local control system, while the central control system continues in operate automatic mode.

3.6.3.4 Architecture of the instrumentation and control system

The nuclear process Instrumentation and control system (EF CC) relates to the waste package handling kinetic process, from the receipt of the transport containers to emplacement of the disposal packages in the ILW-LL and HLW disposal cells. Its function is to supervise and control the nuclear process as a whole based on the different levels of the CIM pyramid, from the field equipment (level 0) to the management of production (level 3) (see figure below).

[51] The instrumentation and control devices ensuring machine safety do not form part of the safety instrumentation and control system.

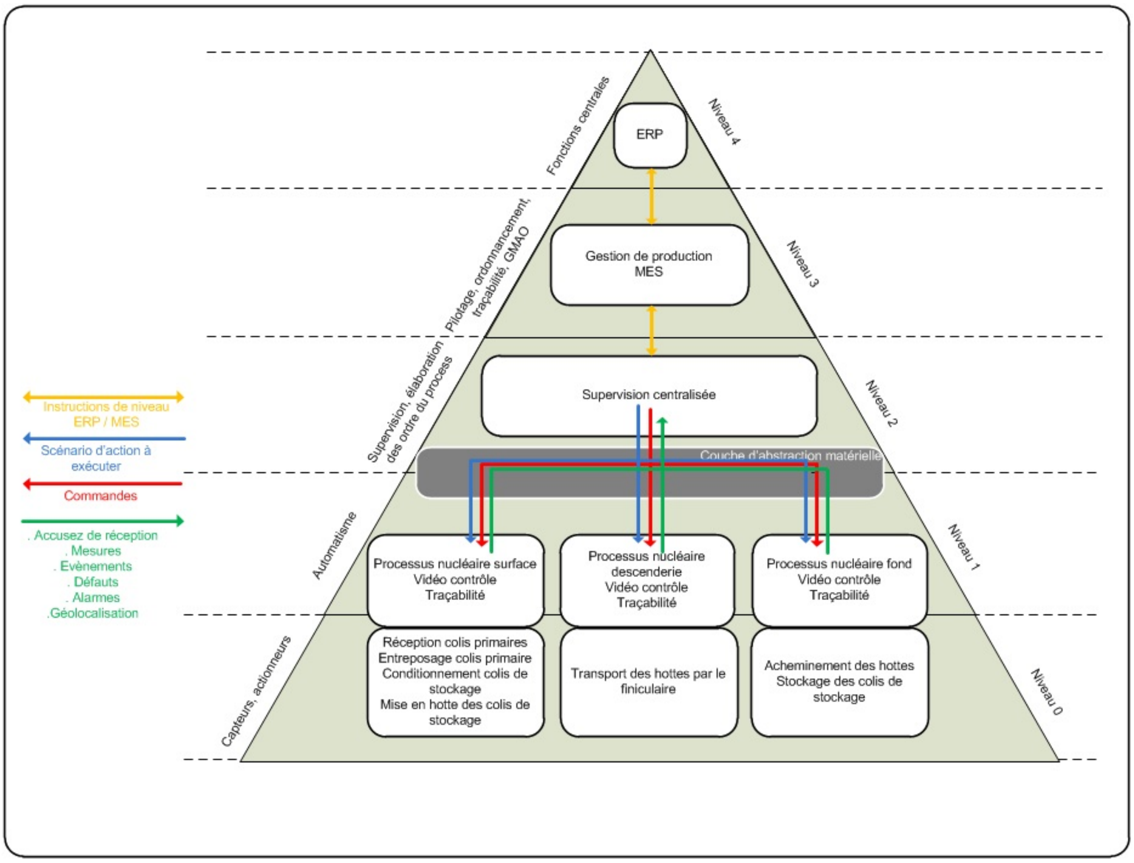

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Figure 3.6-9 CIM pyramid: Principle and logic of the Instrumentation and control system

The following levels are defined:

- Level 0 sensor and actuator level, including in particular the safety actuators (barriers) and safety sensors directly taken into account by the overall process safety system;
- Level 1 (automation) is broken-down into three sub-levels:
  - ✓ a first level of automatic controls incorporated within the equipment to manage their sensors and actuators, as well as the safety functions intrinsic to the equipment items.
  - ✓ a second level of automatic controls to manage the different operations (with the exception of automatic safety controls);
  - ✓ a third level of automatic controls relating to the overall sequencing between production chains and the overall safety aspects.
- Level 2 (control and supervision) containing:
  - ✓ IT resources (redundant servers, etc.) ;
  - ✓ the centralised control points (PCC) and the associated HMIs for operations, the PCCs being located in the centralised control room (SCC) of the nuclear building;
  - ✓ safety functions with specific HMIs.

This level relies on the common resources of the Cigeo industrial information system The equipment or machines of each level and the different levels are interconnected via the secondary networks and the main network of the industrial information systems, networks exclusively dedicated to the instrumentation and control system (fibre optic, high availability redundant ring).

The nuclear process instrumentation and control system covers:

- the nuclear building from the receipt of transport containers to transfer cask emplacement and the second level inspections;
- the horizontal cask transfer systems in the nuclear building and the underground facility (connecting drifts and disposal cell access drifts);
- the ramp transfer equipment of the operating ramp;
- the ILW-LL and HLW waste package cell emplacement equipment;

The instrumentation and control functional unit comprises three functional sub-units (SEF): (i) nuclear process, (ii) video monitoring, (iii) traceability. The Instrumentation and control functional unit implements the nuclear process processing system controlled by a centralised supervision system and local sight control systems:

- reception of primary packages (unloading of transport containers, package inspection);
- Storage of primary packages (if necessary);
- primary package into disposal package emplacement;
- storage of disposal packages;
- emplacement of disposal packages in casks;
- horizontal cask transfer at the surface in the nuclear building;
- loading/unloading of casks in the ramp transfer system at the upper and lower stations;
- the surface-to-underground transfers via the ramp transfer system;
- horizontal cask transfer in the underground facility;
- emplacement of disposal packages in the ILW-LL and HLW disposal cells.

The management of the nuclear process is ensured by automatically controlled gripping, handling and transfer systems. The transfer equipment is fitted with on-board wireless communication devices to enable “real-time” tracking of operations.

The nuclear process instrumentation and control system is handled by process and safety automatic control systems. It is mainly controlled from the Centralised control room (SCC) and if necessary from the local control stations (consoles, HMI on the front of instrumentation and control cabinets).

The video-monitoring system is mainly used in local mode to assist the operation of surface nuclear equipment and remotely (centralised control room (SCC)) for tracking the packages and the transfer cask during movement.

The “traceability” function sub-unit tracks the movement and positioning of packages within the facility in real time, including within the disposal cells.

Production management

The principle of the production management system is based on the MES (Manufacturing Execution System) concept enabling a configurable, expandable monitoring of activities complying with the process management concept. It incorporates a series of functions to ensure consistent and efficient execution of operational activities relating to, traceability and genealogy of work materials, management of materials in process and stocks, execution of instructions, monitoring of operations, setting up of performance indicators (TRS, MTTR, MTBF, etc.) and integration with the CIM level 4 management systems.

The MES concept is elaborated so that each member of the Cigeo operating team obtains the relevant information for his or her level. It provides the means for interoperability between the different departments (management, operational control, maintenance, development, automation, etc.). The main functions provided by MES in Cigeo are:

- modelling of package processing zones (primary package and disposal package): reception, storage, conditioning, transfer of disposal packages to the disposal cell;
- configurable, upgradeable software allowing an approach adapted to the gradual deployment of the underground facility;

- ready-to-use operator interfaces, able to make the system operational while offering the required flexibility, in particular for adapting the interface to the different user profiles;
- traceability and positioning of disposal packages
- dynamic monitoring of operations in progress and stocks;
- flexible management of processing stages;
- automatic collection and archiving of processing data.

3.7 Management of centre's liquid effluent and waste

3.7.1 Effluent management

3.7.1.1 Inventory of effluent

The potential effluents are:

- waste water for which treatment is envisaged as close to the work area as possible;
- operating zone dewatering water;
- rainwater.
- fire extinguishing water.

Principles of effluent management

The schematic diagrams for the management of effluent are presented in appendices 4 and 5, distinguishing between the shaft zone and the ramp zone.

3.7.2 Waste management

The approach for minimising the quantities and the radiotoxicity of the waste produced relies essentially on an optimised choice of materials and the confinement of contaminated substances. The emphasis will be placed as far as possible on the possibility of reusing equipment after upgrade (maintenance aspect).

The management of generated waste will be described in the General Operating Rules (RGE) with a reminder of the provisions for limiting the volume and toxicity, the collection and conditioning processes radiation protection zoning and inspections. In addition, a waste zoning will be defined for the facility. This waste zoning will differentiate between the areas generating conventional waste and those generating nuclear waste or waste categorised as such.

3.7.2.1 Inventory of waste

The surface facilities will essentially produce “technological” waste, linked to the operation and maintenance of the facilities themselves (tools, cables, plastic films, etc.). Most of this waste will be of low radioactivity. They will be collected and conditioned then evacuated to a suitable waste management solution (in principle CSA or Cires).

3.7.2.2 Principles of waste management

The zones will be classified when the design layouts of the facilities have been defined in more detail.

The complete inventory of all the objects or components liable to be activated or contaminated will be constructed at a later stage. For each type of waste generated (nature, origin, type of contamination), a treatment strategy by a suitable waste management solution will need to be defined. Subsequently, an account will be kept of the volumes of waste produced, with yearly balance and a waste report. This will be regularly revised, providing comprehensive feedback on waste management in terms of:

- Limitation of the volumes of waste produced;
- Knowledge and control of waste flows and their characteristics.

4

Operation of Cigeo

4.1 General principles of centre operation

At this stage, and without prejudice for future developments, it is planned to place the operation of Cigeo under the responsibility of a site manager with responsibility for:

- The basic nuclear installation and its operation, namely all the activities associated with the receipt and disposal of packages, the construction of new disposal cells, the maintenance of the installations and the monitoring of the environment, all in compliance with the applicable technical and regulatory requirements;
- The safety of people and goods present within the facility;
- The taking into account of risks associated with organisational and human factors;
- Relations with the authorities on a local level

The site manager will draw on the following five functions:

- Operation: implementation of the technical and human resources necessary to ensure the operation of the installations, the fulfilment of the production programme, for maintaining the equipment in operating condition, nuclear safety, the safety of people, the preservation of the environment;
- Customer interface: development of waste management processes, including acceptability and approval (see following paragraphs), management of customer relations;
- Engineering/Construction: study and management of construction works, fitting-out and commissioning in particular of underground structures (new disposal cells);
- Quality, Health, Safety, Security, Environment (QHSSE): development, management and follow-up of the quality, health, safety, security and environmental policy of the company, on site;
- Support: purchasing, commercial negotiation, general accountancy and cash-flow management, legal support for the different units, operation, maintenance, development and safety of information systems.

The description in this document focuses on the main functions necessary for the operation of the centre. It does not include any discussion of the industrial organisation of Andra during the construction or operating phase, in particular the sub-contracting policy or the implementation of second level lines of inspection at the Agency level, topics that are addressed in the draft of the report on the technical capabilities of the operator.

4.2 The operation function

The operation function incorporates the production and maintenance functions. It is placed under the responsibility of an operations manager supported by a head of production and a head of maintenance. This ensures that the operating and maintenance requirements are taken into account at the appropriate level in order to produce the planned emplacement programmes and to maintain the production equipment in operating condition.

4.2.1.1 The production function

The production function controls the ILW-LL and HLW waste package handling and disposal processes. The waste package disposal process is controlled by teams of operators.

4.2.1.2 Operational support

This function covers all the tasks necessary for production in direct or indirect interface with the operating activities.

Operational support includes the following activities:

- Management of disposal containers (specifications, orders, procurement, etc.). This function will also ensure the management of nuclear material (GMN);
- Management of transport documents;
- Delivery planning department;

- Watchmen and utility management department;
- Operating methods department;
- Operating waste management;
- Modifications of minor importance and construction/operating interfaces.

4.2.1.3 Maintenance

This function, which is charged with maintaining the production capabilities of the different facilities in operating condition, is backed by an organisation based on the trades and specialisations and takes the following forms:

- <u>Preventive maintenance</u> which consists in carrying out regulatory periodic inspections and repairs or which are aimed at ensuring the quality parameters of the equipment concerned;
- <u>Predictive maintenance</u> which consists in initiating maintenance operations following the analysis of certain monitoring parameters in order to avoid incurred failures and maintaining control over production outages;
- <u>Curative maintenance</u> which consists in carrying out a repair to restore equipment to operation following a failure.

Maintenance concerns the following systems:

- Electricity (HV/LV power circuits);
- Communications and security systems (intercom system, video monitoring, telephony, SSI, etc.) ;
- Mechanical and electro-mechanical systems;
- Automation and instrumentation and control systems;
- Hydraulic and pneumatic systems;
- Heating, ventilation and air-conditioning;
- Boiler making, pipework, wood work, locksmiths.

Support and maintenance consists of the following functions: (i) a maintenance operations management office, (ii) a planning unit for organising the maintenance of the different functions or the equipment associated with operating activities, (iii) a methods department, (iv) a general store for the supply of consumables and equipment/components for maintenance.

4.2.1.4 Utility services control

The production/maintenance teams assigned to utility services control operate from the local control rooms incorporated within the utilities buildings. Correct operation and alarm displays enable the operators controlling the nuclear process from the centralised control room to view the status of the utilities necessary for operation.

These alarms are also displayed in the security control centre (PCS) enabling the local safety and security team personnel to initiate the necessary corrective actions outside normal working hours.

4.3 Customer interface function

4.3.1 Waste package management

The management of waste packages is the central activity of the Cigeo operating personnel (performing the “Operator function” and the “Customer interface function). It combines the activities necessary for establishing agreements between Andra and the waste producers for organising and authorising the reception of packages on the Cigeo site, together with the Cigeo operating activities (from the reception of waste packages to their final emplacement in the disposal cell). These activities are organised into two processes as follows:

- An acceptability process: this process starts from the moment a waste producer requests a family of primary packages to be received at Cigeo and ends with the issuing of the acceptance of the packages at Cigeo. This process ensures that approval and acceptance of a family of packages within the repository is only granted after verification by Andra that packages comply with the applicable Cigeo reference document. This applicable reference document contains in particular the package acceptance specifications;

- An operational control process.

Cigeo package acceptance specifications

Andra considers that the primary waste package is an element important for the protection of the interests referred to within the meaning of the Order of 7 February 2012 on basic nuclear installations [1]. Requirements of a qualitative, quantitative or declarative nature are therefore contained within the package acceptance specifications referred to in article L.542-12 of the French Environmental Code.

The requirements are specified for the primary waste packages and result from the consideration of the safety of Cigeo during its operation and after closure, as well as the operational, safety, health and environmental protection requirements.

They form part of the Cigeo operating reference document.

4.3.2 The acceptability process

The acceptability process enables the operator of Cigeo to manage the flow of waste packages throughout the period of operation and in accordance with the general operating rules. This process may last for several years (from the date of the approval application to the acceptance of the final package of a family of packages).

This process in particular leads to:

- The issuing of an approval for a family of packages from the Cigeo operator to the waste producer in the form of a generic agreement on the provisions relating to the conditioning of radioactive waste. This approval is backed by the acceptance specification applicable at the date of its enactment and may contain quality control provisions (including inspections) to be implemented for delivery;
- The issuing of a delivery agreement that depends on the satisfactory results of the previous verifications;
- The issuing of an acceptance: act via which the Cigeo operator confirms his agreement to dispose a radioactive waste package within its facility. The acceptance will be enacted following the package inspections carried out at Cigeo.

This acceptability process is based on the following package quality control provisions:

- The verification of documents justifying compliance of the packages supplied by the waste generator with the acceptance specifications. These documents may be based, in particular, on the production specifications, the process description, the declaration of package characteristics, the process and waste package control plan;
- Random package inspections, implemented prior agreement for the delivery of a waste package family to Cigeo. Two options are envisaged:
  - ✓ These inspections are conducted on the waste producer 's site (on the production line or in an inspection facility);
  - ✓ These inspections are performed at the Cigeo site on packages selected beforehand by the Cigeo operator.
- On-line inspections at the Cigeo site performed upon package reception;
- Technical tests;
- Andra monitoring at the producer's waste generating and package storage sites;
- Audits.

In the event that a deviation is detected, Andra will analyse the nature of the deviation according to two criteria: (i) the severity and (ii) the number of packages concerned. Depending on the result of the analysis and according to the stage of the process at which it is detected, Andra reserves the right to either:

- Request correction of the deviation by the producer;
- Suspend the programme of shipment currently in progress;
- Treat the package at Cigeo;
- Issue a waiver following investigation of the non-compliance;
- Return the package to the producer.

In any event, the Cigeo operator will enter into discussions with the producer in order to find a disposal solution for the package or package family concerned. The solutions will consist in assessing whether it is preferable to change the method of waste conditioning or to develop a specific disposal container for Cigeo in the light of the technical and economic issues.

According to the nature of the deviation and following an appropriate safety analysis (for example as part of an internal authorisation process), the package is placed in a buffer zone (if the deviation is deemed acceptable for entry into the buffer zone to await treatment) or in a multi-operation zone (if the deviation is “unacceptable”). Exceptionally, non-complying packages may be returned to the sender if the reconditioning operations cannot be undertaken at the Cigeo site. The verifications and, if applicable, package preparation for transport would be carried out by the Cigeo teams in conjunction with the teams of the producer concerned and of the carrier.

Non-complying packages placed in the buffer will be identified as such and placed in a reserved area of the buffer zone. Specific operating instructions will be drawn up if necessary (no overhead pass, lockout/tagout, etc.).

Andra and the producers have already begin joint discussions to define the package quality control strategy which will be adopted at the end of the detailed engineering design stage, as well as the technical and organisational measures which will be taken to apply this strategy. This joint elaboration should ensure that the rules so defined are objective and shared.

The main objectives to be achieved as part of the elaboration of the acceptability process are:

- To guarantee the compliance of the waste packages for the disposal solution adopted;
- To adapt the disposal centre‘s waste package quality control provisions to the variability of the quality control process implemented by a producer, both in, terms of organisation and provisions;
- To meet the requirements of the ASN decision on the conditioning of the waste packages;
- To track all information issued or received;
- To organise the package flow to suit the delivery schedule which will be defined in coordination by the producers and the disposal centre (PIGD type);
- To control the cost of the process.

An initial version of this acceptability process will be finalised for the construction licence application.

4.4 The engineering/construction function

In connection with the design/construction studies, the engineering/construction function defines the technical specifications of the works and the equipment, ensure the technical management of the suppliers, controls the correct completion of the works on time and at cost.

It ensures the commissioning and the handover of the “new” facilities to the operator in accordance with the operating expectations and requirements.

4.5 The Quality, Health, Security, Safety and Environmental (QHSSE) function

The different functions combine the following activities:

- Quality: Developing the Cigeo quality policy in conjunction with the quality department of the agency. Setting-up and ensuring the application of the integrated management system by the various internal and external actors. Producing and updating the associated documentation. Monitoring improvement indicators and progress.

- Safety: Controlling risks and managing all the technical provisions and organisational measures taken in order to prevent accidents and mitigate their effects. It includes radiation protection, prevention and la fight against malicious acts.
- Health: Medical supervision of employees, management of medical examinations and analyses, monitoring of health around the site.
- Security: Developing the security policy of the agency during the construction and operating phases. Setting the objectives and defining the processes for achieving the occupational safety commitments. Setting out and managing the worker safety policy. Nuclear material tracking and accountancy.
- Environment: Managing the environmental policy. Controlling the environmental impact during the construction and operating phase. Carrying out sampling, analyses and assessments. Presentation to the authorities.
- Radiation protection: Radiological control and monitoring of personnel, management of dosimetry and activity measuring equipment of facilities, radiological inspection of waste, environmental sampling and analyses.

The safety engineers are continuously present within the facility, reporting to the various managers. They will be responsible for ensuring compliance with the safety rules to be applied by the control and maintenance operators each day in the field. They will participate in the validation of the operating and maintenance procedures and the analyses of all changes to equipment or operating procedures for which they will provide a safety opinion. The safety engineers are also responsible for assisting the operational teams to prepare exceptional maintenance operations.

The safety function covers:

- Assistance to operating teams;
- Assistance to contractor teams and monitoring of safety requirements for construction/ commissioning of new disposal cells;
- The development and follow-up of the Cigeo safety reference document (safety report, on-site emergency plan, acceptance specifications, etc.);
- The management and follow-up of the Cigeo safety studies in particular in connection with design modifications,
- The assessment of possible changes to the reference documents, equipment, if applicable as part of the internal authorisations procedures [52];
- The keeping of an operational feedback database;
- The drafting of periodic disposal centre activity assessment reports;
- The safety review.

The radiation protection function covers:

- Radiological control and monitoring of personnel and rooms;
- The management of dosimeters and activity measuring instruments of the facility;
- Radiological control of waste
- Environmental sampling;
- Methods.

The health physics technicians are also present in the facility on a daily basis. The equipment operating, maintenance and modification procedures will be systematically examined by the health physics technicians. The health physics technicians are responsible for the prevention plans, for training and for informing the personnel about radiological hazards.

[52] The internal authorisation may only be processed once the ASN decision authorising Andra has been enacted and according to the established criteria (this is currently the case for the CSA and the CSM waste disposal facilities).

The security function covers:

- The management of coordinated construction/operating activities within the new disposal cell construction and testing zone;
- Physical site protection, emergency response (including fire-fighting), and site security activities. Site security involves the following tasks within the shaft and ramp zone:
  - ✓ Entry and exit control of personnel working within these zones;
  - ✓ Entry and exit control of vehicles;
  - ✓ Inspection of rail and road convoys carrying transport containers;
  - ✓ Control of the entry of potentially hazardous materials (toxic, radioactive, flammable, corrosive or explosive materials (French acronym: TRICE));
  - ✓ Preventing the theft of goods, sensitive information and materials;

The fire control tasks consist in responding to fire alarms and/or outbreaks throughout the Cigeo site facilities. The facilities are under dual surveillance ensured by

- - The centralised control room which collects all the information necessary for the operation of the facilities;
- -The local safety and security team which is responsible for emergency response in the different facilities;
- -The distinctive feature of Cigeo is that it also includes an underground facility. This specificity requires a special organisation and provisions to be defined in order to optimise the response times.

The different lines of action include limiting the speed of lifts, the concept of lift prioritisation in the event of an alarm, the type and number of equipment items in the drifts and the training of personnel as “first aid team members”.

The occupational safety function covers:

- Preventive actions;
- The analysis of pre-accidents and accidents;
- Implementation and follow-up of corrective actions;
- Organisation of training;
- Drawing -up of safety reports.

The health function covers:

- Medical supervision of employees
- Treatment of personnel in the medical facilities (shaft zone and ramp zone infirmaries) in the event of accident or illness, and organisation of transfer to hospital if required.

The environmental function covers:

- The site environmental monitoring activities;
- Environmental sampling and analyses;
- Training of personnel.

The quality function covers:

- The implementation of operating procedures;
- Audit activities;
- Awareness-raining actions.

4.6 The support function

The support function comprises the various departments (purchasing, accountancy/finance, management control, legal and information system) serving to ensure the administrative and financial management of Andra. The roles are mainly to control the overall management of the Agency, to put in place the management tools; ensure all legal support in connection with business law, insurance, urban planning and nuclear matters, to operate, maintain and develop the information system and to ensure the safety of the computer system.

It also includes the human resources function which plays a role in and implements the Agency's human resources policy and programme in conjunction with the “Corporate” function. As part of its regional integration policy, the human resources function actively participates in the development of the local jobs market in collaboration with the different local administrations and businesses.

VOLUME III SAFETY OPTIONS RELATING TO WASTE PACKAGE TRANSFER AND EMPLACEMENT OPERATIONS

1

Summary of Waste Package Transfer and Emplacement Operations

1.1 Overview of operations involving waste packages

The figures below illustrate all the processes, particularly the routing of waste packages in the surface facilities and up to their emplacement in the waste repository, based on the process descriptions in Chapter 3.

The entire Cigeo nuclear process centres on the ramp zone surface facility, the waste package transfer ramp and the underground facility.

During the process, which extends from the reception of transport containers containing waste packages coming from producers up to the emplacement of disposal packages in disposal cells and tunnels, the radioactive loads handled are in the following forms:

- transport containers (ET) containing waste packages from producers;
- primary waste or disposal packages;
- transfer casks containing disposal packages.

These figures are not a substitute for the descriptions in Chapter 3 of Volume II. Their main purpose is to provide a visual representation of how waste packages are unloaded, processed and transferred on arrival at Cigeo at the surface, transferred to the ramp, then into the drifts before being placed in the disposal cells and tunnels. The above operations take place in the ramp zone nuclear surface facility, the waste package transfer ramp and the underground facility respectively.

1.2 Surface operations

The figures below outline all the processes that are carried out at the nuclear surface facility in the ramp zone, as well as the areas through which radioactive loads (waste packages, casks, containers) transit.

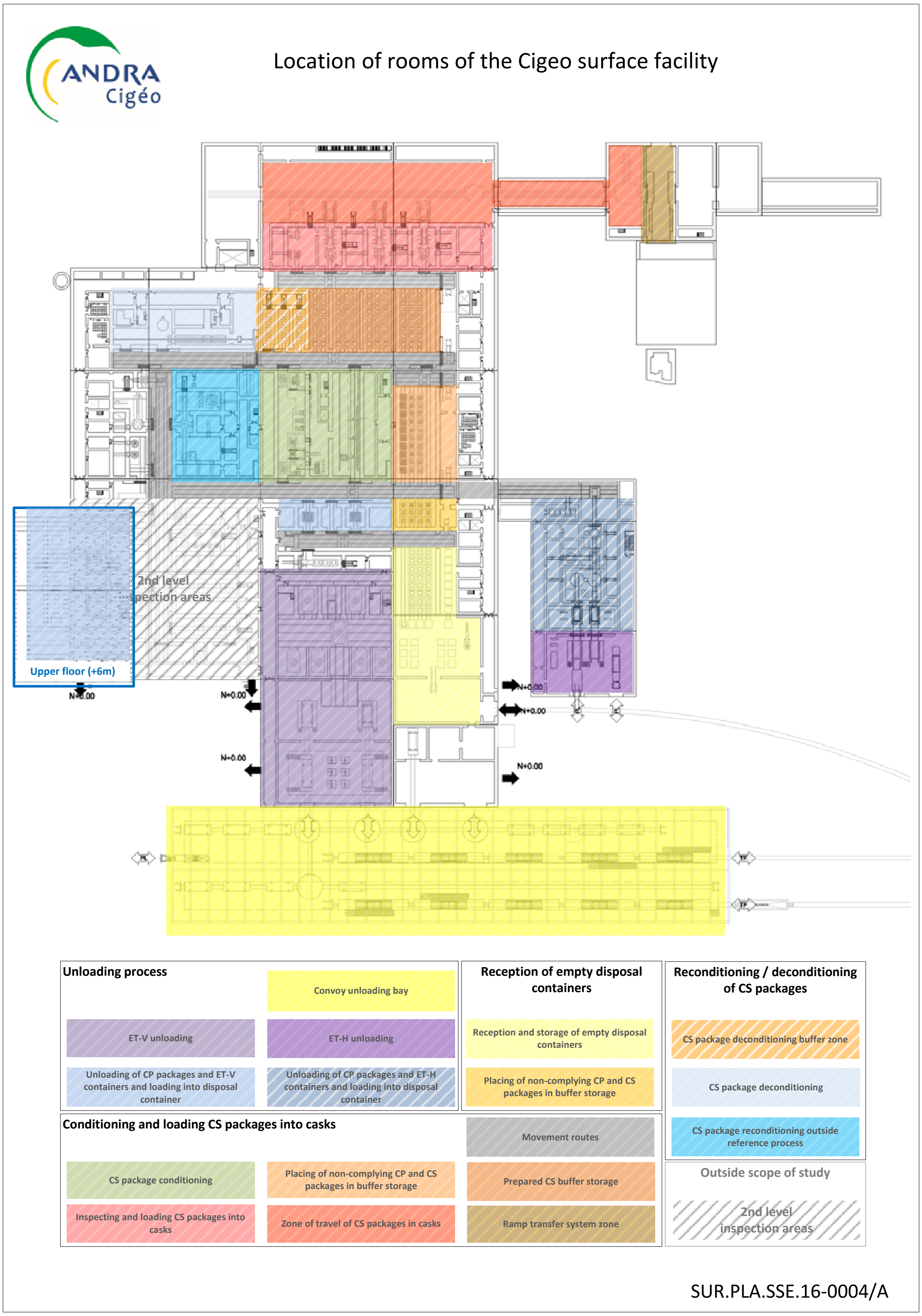

Figure 1.2-1 *Cigeo ramp zone surface facility - Location of various rooms through which waste packages transit*

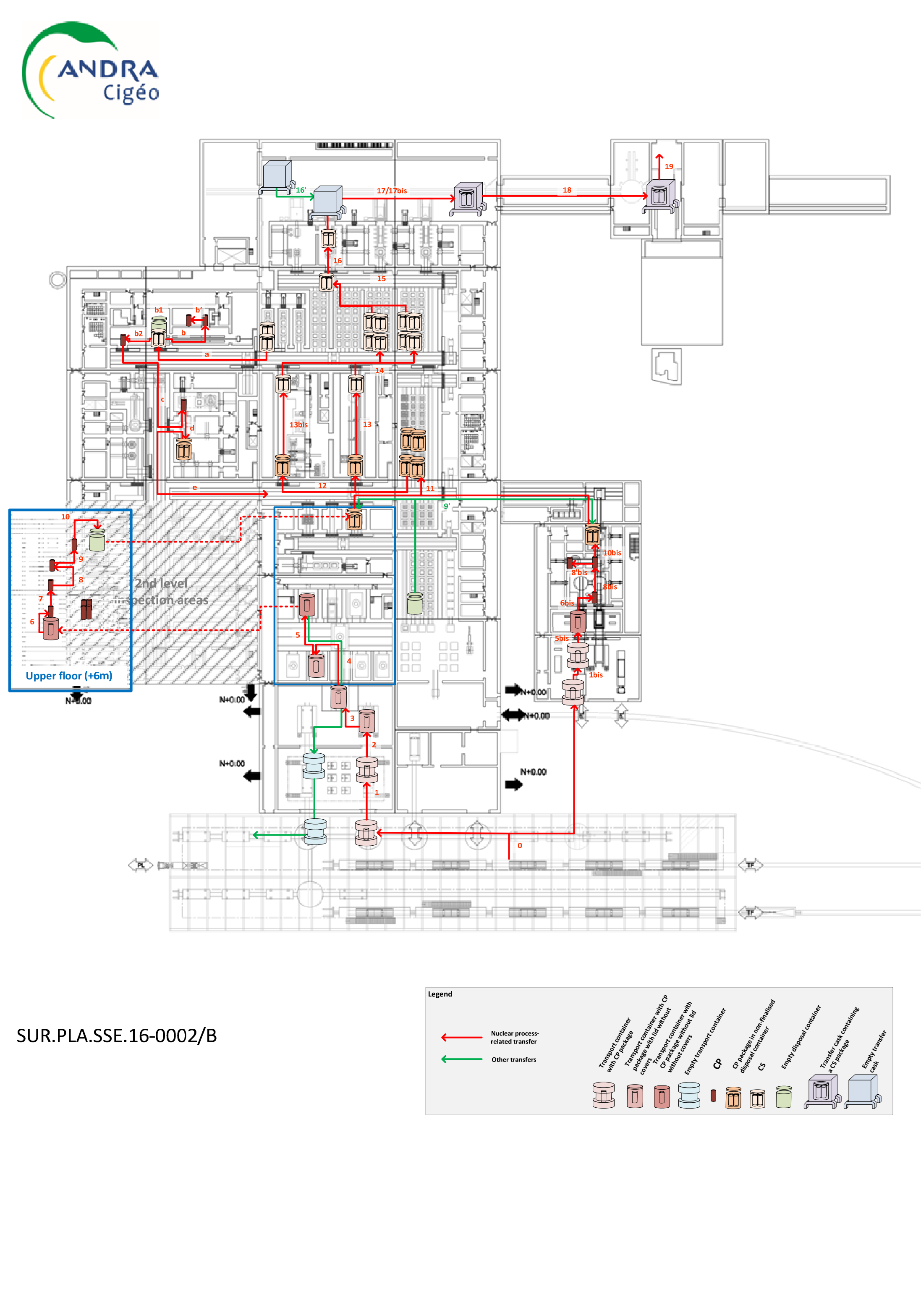

Figure 1.2-2 *Cigeo ramp zone surface facility - Location of various rooms through which waste packages transit*

List of stages in the handling process -Surface-

Main process: vertical transport containers (ET-V)		
0	Train (un)loading bay	Transferring the full ET-V to the frame/rail lorry via the gantry crane
1	Train (un)loading bay ET receiving area 1	Transferring the rail lorry + frame with the full ET-V from the train (un)loading bay to the upstream C3 inspection station
2	ET receiving area 1 ET receiving area 2	Transferring the full ET-V from the C3 inspection station to the upstream station for ET-V vertical positioning
3	ET receiving area 2	Tipping the ET-V and loading it on the transfer cart
4	Cart access corridor Transfer carriage movement ET-V preparation and docking rooms	Transferring the transfer cart to the preparation station on the transfer carriage
5	ET-V preparation room Preparation room/C4 inspection	ET-V preparation (C4 inspection)
6	Unloading cell	Unpacking: taking the CPs from the ET and placing them on the cart (max. capacity of 16 CPs)
7	Unloading cell C5 inspection cell	Transferring the cart to the C5 inspection station
8	C5 inspection cell	Placing the CP in the cart and setting it down in the C5 inspection cell
9	C5 inspection cell	Transferring the CP in the cart and setting it down in the buffer storage zone; Installing the empty CtS on the pallet (or in the HLW basket); Removing the lid and opening the hatch
10	C5 inspection cell Cells where CPs are placed in CSs	Taking the CP and placing it in the CtS
11	Unprepared CS buffer storage	Transferring the unprepared CS cart to the unprepared CS buffer storage zone (on the transfer carriage)
12	CP in unprepared CS buffer storage zone	Transferring the CS/CP cart with the buffer stock C5 inspection pallet to the upstream ILW-LL conditioning area (on the transfer carriage)
13	ILW-LL CS conditioning cell	ILW-LL CS conditioning operations - removing the CS lid, filling voids, screwing down the lid, concrete jointing and C6 inspection
13b	HLW CS conditioning cell	HLW CS conditioning operations: welding brushing, heat treatment, C6 inspection
14	Process circulation corridor Prepared CS buffer storage	Transferring the prepared CS pallet to the buffer storage zone (on the transfer carriage)
15	Process circulation corridor C7 inspection cell	Transferring the prepared CS pallet to the C7 inspection cell (on the transfer carriage)
16	Cask loading cell	Transferring the prepared CS to the cask loading cell
17	ILW-LL cask loading cell/cask storage area	Transferring the CS to the loading table Loading the CS in the ILW-LL cask and undocking
17b	HLW cask loading room/cask storage area	Tipping the HLW CS Loading the CS in the HLW cask and undocking
18	Full and empty cask storage area/Connecting drift to ramp head	Transferring the cask to the ramp transfer system by shuttle via the turntable and connecting drift
19	Package ramp head	Loading the cask on the ramp transfer system
Main process: Horizontal transport container variant		
X bis	Horizontal transport container building (DN 0191)	*(Refer to operations 0 to 10 above)*
Non-compliant disposal container (CS) management process		
a	Non-compliant container storage area Non-compliant CS receiving cell	Storing the non-compliant CSs (after C6 inspection) and transferring them to the non-compliance management cell
b1	Non-compliant HLW CS deconditioning cell	HLW CS deconditioning
b2	Non-compliant ILW-LL CS deconditioning cell	ILW-LL CS deconditioning
b'	CP inspection and decontamination cell	CP inspection and decontamination
c	Transfer to the C5 inspection cell	C5 inspection
d	CS conditioning cell	Placing the CPs in the CSs
e	Transfer carriage movement	Transferring the unprepared CS cart to the buffer storage zone

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Figure 1.2-3 Cigeo ramp zone surface facility - List of stages in the waste package handling process

1.3 Waste package transfer from the surface up to emplacement in disposal cells and tunnels

The figure below summarises waste package transfer operations in the waste package ramp, and then in the underground facility (connecting drifts, access drifts and emplacement in disposal cells and tunnels).

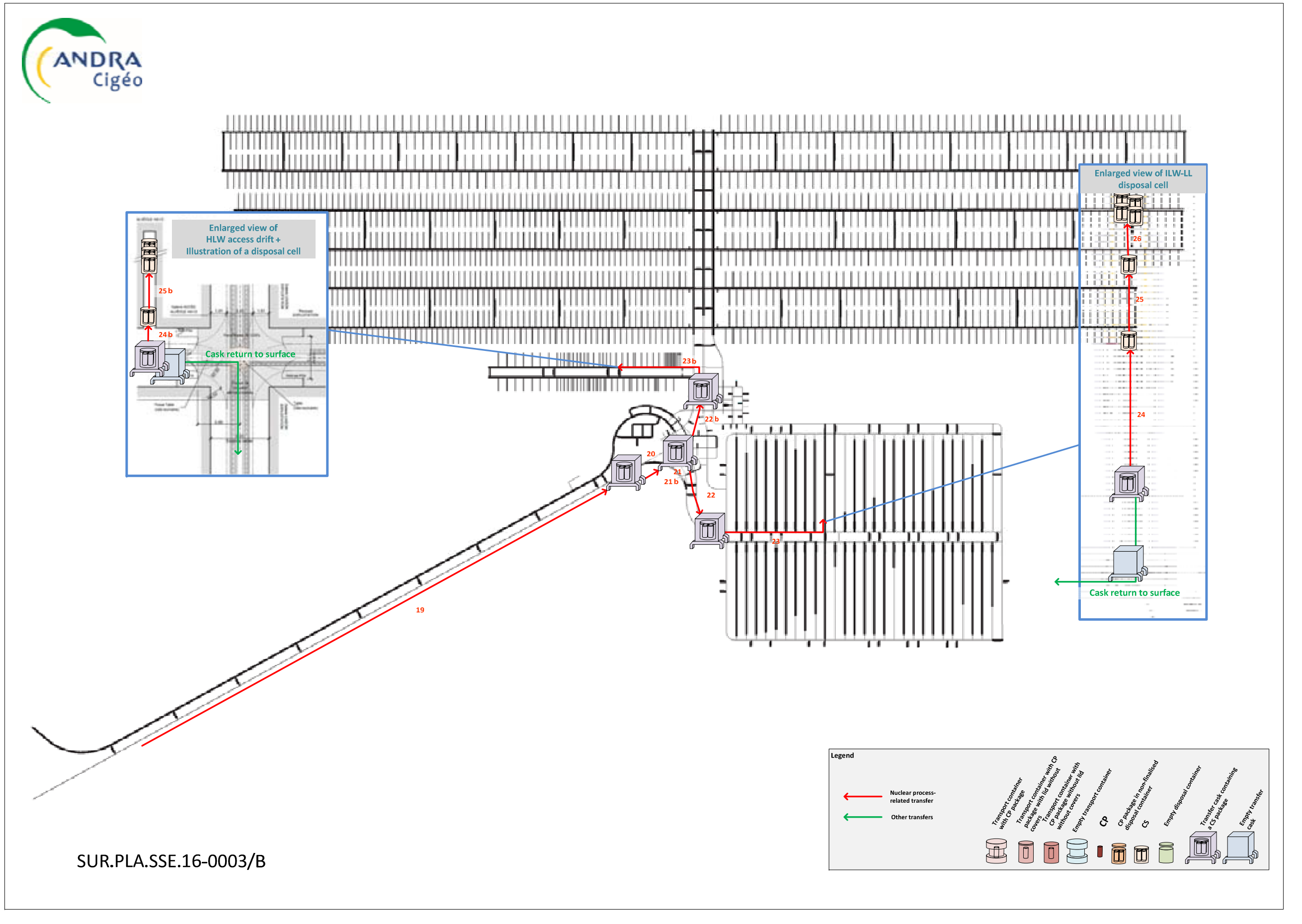

Figure 1.3-1 Waste package ramp and underground facility - Waste package transfer to disposal cells and tunnels

List of stages in the handling process
-Bottom-

ILW-LL disposal container (CS) handling and transfer process		
19	Package transfer ramp	Transferring the cask via the ramp transfer system
20	Bottom of package transfer ramp	Arrival of the ramp transfer system at the bottom station
21	Bottom station in the logistics support zone	Loading the cask on the underground transfer cart
22	Connecting drifts	Transferring the cask using the underground transfer cart Turning the underground transfer cart on the turntables at intersections
23	Intersection between connecting drift and ILW-LL access drifts	Placing the cask opposite the access drift Withdrawing the underground transfer cart Turning the rail turntable Loading the cask on an ILW-LL shuttle
24	ILW-LL access drift	Transferring and placing the ILW-LL CSs on the docking table Docking the cask to the docking façade
25	ILW-LL handling room	Opening the cask and the docking façade Unloading the CS on the receiving table Transfer to the lift table
26	ILW-LL disposal tunnel	Lifting the CS to the required height on the lift table Picking up the CS using the stacker crane Positioning the CS in the disposal tunnel
Disposal container (CS) handling and transfer process: HLW CS variant		
21bis	Logistic support zone (ZSL)	Loading the cask on the underground transfer cart
22bis	Connecting drifts	Transferring the cask on the underground transfer cart Turning the cart on the turntables at intersections
23 bis	Intersection between linking drift and HLW access drift	Placing the cask opposite the access drift Withdrawing the underground transfer cart Turning the rail turntable Loading the cask on an HLW shuttle
24 bis	HLW access drift HLV disposal cell	Docking HLW cask Removing the operating plug Transferring the cask to position the CS opposite the head of the disposal cell Placing the HLV CS at the head of the disposal cell and withdrawing the empty cask Refitting the operating plug
25 bis	HLW disposal cell	Docking the pusher robot Removing the operating plug Transferring the cask to position the pusher robot opposite the head of the disposal cell Transferring the HLW CS at the back of the disposal cell Refitting the operating plug using the pusher robot

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Figure 1.3-2 Cigeo waste package ramp and underground facility - List of waste package handling operations

2

Inventory of Risks and Risk Management Provisions

2.1 Internal nuclear risks

2.1.1 External and internal exposure

2.1.1.1 Source of risk

External exposure

In normal and incident/accident operating conditions, the risk of external exposure is associated with source terms consisting of waste packages containing radioactive materials that emit ionising radiation.

The main ionising radiation source terms are the ILW-LL and HLW packages received at the Cigeo site. These waste packages are in the form of primary waste packages, then disposal packages. Their radiological characteristics vary considerably (see Volume II, chapter on waste packages). They may be activation products, fissile material, fission products, or sealed sources, and can emit α, β, and γ radiation and neutrons.

- ***Ramp zone surface facility***

The risk of external exposure is associated with the radiological source terms located in the ramp zone facility rooms, particularly the nuclear building. Table 2.1- lists the radiological source terms for each room or type of room.

Table 2.1-1 Surface facility rooms containing radiological source terms

Room or type of room	Source terms
Halls 1/2/3 used for receiving and preparing transport containers up to the docking point at the disposal cells.	Waste packages in B-type and A-type transport containers (ET)
Non-compliant transport container processing room	Waste packages in B-type and A-type transport containers (ET)
Waste package unloading, inspection and loading cells	Unprepared disposal packages
Unprepared disposal package buffer zone	Unprepared disposal packages
Cells for conditioning in prepared disposal packages	Prepared disposal packages
Prepared disposal package buffer zone	Prepared disposal packages
Disposal package deconditioning cell	Unprepared and prepared disposal packages
Disposal package cask loading cell	Prepared disposal packages
Cask storage area and waste package ramp head	Disposal packages in HLW and ILW-LL casks
Disposal cell and tunnel HEPA filter rooms	HEPA filters loaded with radioactive aerosols
Hot stores and workshops	Contaminated equipment and components
Processing room for waste from processing cells, nuclear operating waste drum storage room	Nuclear waste
Buffer tanks for potentially radioactive effluents	Potentially radioactive effluents
Laboratory for analysis, spectrometry	Nuclear waste samples

During the operating phase, the main operations in the surface facilities that are likely to induce the risk of exposure to ionising radiation are:

- operations requiring the presence of operators close to radiological source terms:
  - ✓ receiving and unloading trains and trucks;
  - ✓ preparing and unloading containers;
- operations requiring the occasional presence of operators close to radiological source terms:
  - ✓ waste management and effluent processing operations;
  - ✓ radiation protection inspection/monitoring operations (inspecting containers, monitoring construction areas, monitoring personnel, etc.).

The risks of exposure in incident or accident operating conditions are associated with work carried out close to radiological source terms (transport containers or casks containing waste packages, etc.).

- ***Surface-bottom connections and waste package transfer ramp***

The main source terms that emit ionising radiation on the waste package transfer ramp are:

- disposal packages placed in a cask that is primarily designed to ensure radiation protection. Casks loaded with waste packages are transferred automatically by a ramp transfer system;
- gas or liquid effluents likely to be contaminated and potentially radioactive solid waste transferred via surface-bottom connections towards the storage, sorting and removal zones located at the surface.

Operations performed under normal operating conditions do not involve exposure to ionising radiation because:

- casks are transferred automatically and supervised remotely;
- liquid effluents and solid waste are not contaminated;
- radioactive gaseous effluents are channelled to the outlet at the surface via the dedicated shaft for exhaust air return in the operating zone (VVE);
- maintenance of the ramp transfer system is scheduled for periods when no waste packages are present.

At the current stage of studies, Table 2.1- shows the radiological source terms present in surface-bottom connections.

Table 2.1-2 Radiological source terms present in surface-bottom connections

Room or type of room	Source terms
Waste package transfer ramp	Disposal packages (in cask)
Waste package transfer ramp	Potentially contaminated effluents and waste

There is a risk of exposure for personnel in incident or accident situations that require work to be carried out in contact with the ramp transfer system when it is loaded with a cask containing a waste package, or work involving potentially contaminated solid waste or effluents.

- ***Underground facility***

Radiological source terms identified in the underground facility are as follows:

- disposal packages inside casks, disposal packages located in handling cells and disposal packages placed in ILW-LL and HLW disposal cells;
- potentially contaminated gas and liquid effluents and non-conventional solid waste stored before being sent to the surface facility for processing and removal.

At the current stage of studies, Table 2.1- shows the radiological source terms that are potentially present in each room or type of room in the underground facility.

Table 2.1-3 Rooms in the underground facility containing radiological source terms

Room or type of room	Source terms
Access drifts, connecting drifts	Disposal packages (in cask)
Handling cells	Disposal packages (ILW-LL)
ILW-LL disposal cells	Disposal packages (ILW-LL)
HLW disposal cells	Disposal packages (HLW)
Waste buffer zone in "operating" logistics support zone	Nuclear waste
Filtration rooms	HEPA filters loaded with radioactive aerosols
ILW-LL and HLW sections	Potentially contaminated effluents

During the operating phase, the main operations involving a risk of exposure to ionising radiation in underground facility zones are:

- work on replacing ventilation filters in ILW-LL disposal cells;
- radiation protection monitoring operations (inspecting casks, monitoring ambient conditions in construction areas, monitoring personnel, etc.).

In normal operation, liquid effluents and solid waste are not contaminated.

The risks of exposure in incident or accident operating conditions are associated with operations performed close to radiological source terms (casks containing waste packages, handling cell close to a disposal cell containing waste packages).

<u>Internal exposure</u>

The risk of internal exposure in normal operation is mainly associated with removable contamination on the outer surface of waste packages that is resuspended in the air or transferred by direct contact. Under incident/accident operating conditions, the risk of internal exposure is largely associated with a loss of containment of a waste package or of other equipment containing radioactive materials.

Containment of radioactive materials is ensured upstream of conditioning by primary packages, and downstream of conditioning by the disposal package. ILW-LL packages are likely to emit radioactive gases (tritium, carbon-14, krypton, etc.). However, HLW primary packages, and therefore HLW disposal packages, are sealed and ensure the containment of radioactive gases. The risk of internal exposure by inhaling radioactive gases nevertheless remains very low compared with the risks of external exposure (dose rate for ILW-LL packages is approximately ten sieverts at the most).

Other sources of radiation at Cigeo facilities include sources used for checking and calibrating radiological monitoring and inspection equipment, ventilation system filters likely to trap radioactive aerosols, and liquid effluents and potentially contaminated waste resulting from facility operation.

2.1.1.2 Safety requirements

Andra follows the recommendations of the International Commission on Radiological Protection (ICRP) applicable to radioactive waste disposal facilities. The optimisation principle (ALARA), with dose constraints, applies to the protection of the personnel and the public against ionising radiation while Cigeo is in operation, taking economic and social factors into account. The dose concepts used in the context of radiation protection are defined in the French Public Health Code (R. 1333-8 and R. 1333-1(25))

The protection objectives for Cigeo under normal and degraded operating conditions, as well as those considered for incident and accident operating conditions are presented in Volume I.

In order to meet the objectives in this table, radiation protection devices are installed between the radioactive source terms and personnel. The materials and thicknesses of these devices are adapted to the radiological characteristics of the source terms, the personnel present and the estimated time spent at the work stations. In Cigeo nuclear zones, for example, the design values for radiation protection devices are about 3.5 µSv.h-1 for permanent work stations (1,500 hours presence per year) and 25 µSv.h-1 for non-permanent work stations (waste package transfer casks).

An initial dose assessment is then performed for the different work stations. The purpose of this assessment is to check that the dose objectives defined by Andra are met and to identify work stations with the highest doses. Optimisation of these work stations will take priority as part of the ALARA approach, which will be implemented iteratively for subsequent studies.

Furthermore, radiation protection zoning is set up on the Cigeo site to prevent risks of external and internal exposure. Radiological zoning is based on regulations, in particular Article R.4451-18 of the French Labour Code and the Order of 15 May 2006 on the identification and marking of supervised, specially controlled or prohibited areas. This zoning, described below, takes into account external exposure with the dose equivalent rate and internal exposure with atmospheric contamination in the air.

2.1.1.3 Preventive measures

For external exposure, the main preventive measures implemented at Cigeo are as follows:

- specifications regarding waste package acceptance and incoming inspections on vehicles transporting radioactive materials (documentation, monitoring dose equivalent rates and contamination of accessible areas) that ensure that operator exposure levels are as expected and compatible with those for which the facility is designed;
- civil works and equipment (shielded doors and windows, docking facades, radiation protection plugs of HLW disposal cells, concrete blocks for closing ILW-LL disposal cells) in the surface and underground facilities, which are designed to make exposure as low as reasonably possible for the personnel and public;
- use of shielded casks that help to ensure radiation protection from the time the disposal package is loaded at the surface, up to the docking point at the head of the disposal cell, via the waste package ramp. The four shielded casks (three for ILW-LL packages and one for HLW packages), are designed to ensure that exposure levels at a distance of one metre are occasionally allow the presence of operators nearby for certain operations;
- handling operations performed directly on primary packages (unloading transport containers, preparing disposal packages, etc.) or disposal packages (storing waste packages, transfer and emplacement in disposal cells, etc.) are automated and supervised remotely from a central control room;
- the entrances to cells and rooms containing waste packages are kept closed mechanically when a package is detected (ambient conditions monitor). If a waste package is present, the instrumentation and control system prevents the door from being opened. Access is subject to information on the ambient dose rate inside the cell;
- routes for waste packages are separate from those used by personnel. In surface-bottom connections, for example, casks containing waste packages travel via the "waste package ramp",

while the personnel take the operating shaft in the shaft zone and the "service ramp" during maintenance and other operations, the two ramps being sixty metres apart;

- maintenance operations performed in the absence of exposure source terms nearby. In addition, design seeks to eliminate or minimise the presence of equipment likely to require maintenance in high-exposure zones. If access to a shielded cell is necessary (for maintenance operations, for example), the cell will be downgraded after checking that there are no waste packages inside it (or, if necessary, in the adjoining cells) and ensuring that no waste packages can be brought in during the maintenance work;
- in the event of incidents or accidents, design will ensure that operators or emergency personnel do not need to enter rooms where exposure exceeds regulatory thresholds (e.g. by providing for a remotely-activated fire extinguishing system);
- radiological zoning is used to indicate and characterise the risk of exposure and prohibit the presence of unexposed personnel in regulated or controlled areas
- regulatory training will be provided at regular intervals to ensure that the personnel are aware of the risk of exposure to ionising radiation.

The preventive measures implemented at Cigeo regarding internal exposure are as follows:

- static containment provided by transport containers, primary packages, disposal packages, ILW-LL transfer casks, walls and openings of rooms and ILW-LL disposal cells. These measures are designed to provide one or more containment barriers, which ensure that contaminants are confined or trapped;
- contamination checks are performed on transport containers, primary packages, disposal packages and casks to detect the potential presence of contamination and, where applicable, determine whether or not decontamination is required;
- use of nuclear ventilation to ensure dynamic containment in rooms where there is a risk of contamination spreading. This containment captures radioactive gases and aerosols and routes them through dedicated ventilation systems and filters aerosols before release to the environment;
- implementation of waste zoning to ensure radiological cleanliness, by separating zones with a potential contamination risk from conventional zones, and by mandatory contamination checks at zone boundaries. It is used to identify and mark rooms where there is a potential risk of internal exposure.

At the current stage of studies, incident or accident conditions calling for human intervention are taken into consideration by implementing the following preventive measures.

<u>Radiological zoning</u>

At the current stage of studies, radiological zoning is mainly concerned with the risk of external exposure. In normal operation, the risk of internal exposure associated with residual surface contamination of waste packages is very slight.

The radiological zoning[53] implemented in the facilities is shown in Table 2.1- for the surface facility, in Table 2.1- for surface-bottom connections and in

[53] The red controlled area identified for cells, corridors, handling cells and disposal cells is an intermittent zoning provision allowing the area to be downgraded when no waste packages are present.

Table 2.1-

Table 2.1-

Table 2.1- for the underground facility. The surface facility zoning plans can be found in Appendices 2, 3 and 4.

Table 2.1-4 Radiological zoning in surface facility rooms

Rooms	Classification
Front zone and rear zone airlock for entry/exit, and circulation corridors	Supervised zone
Edge of "disposal container buffer" room	Supervised area
Front zone of cells	Green controlled area
Rear zone of cell plugs door	Green controlled area
Technical rooms adjacent to process rooms	Supervised area
Nuclear ventilation room of first filtration level, last filtration level	Green controlled area
Spectrometry room	Supervised area
Analysis laboratory	Supervised area
Hot workshops	Green controlled area
Processing rooms for waste produced	Yellow controlled area
Rear zone of cart, Rear zone of transfer carriage	Yellow controlled area
Operating waste package storage room	Yellow controlled area
Train/truck receiving area	Green controlled area
Train/truck receiving area walkway	Yellow controlled area
Transport container receiving area	Yellow controlled area
Transport container preparation and docking rooms	Yellow controlled area
Upper airlocks	Yellow controlled area
Hoists	Yellow controlled area
"Process" cells and corridors	Red controlled area
Non-destructive examination cell	Red controlled area
Ramp head	Green controlled area

Table 2.1-5 Radiological zoning in surface-bottom connections

Rooms	Classification
Waste package ramp	Green controlled area
Service ramp, personnel shaft and equipment shaft	Supervised area

Table 2.1-6 Radiological zoning of rooms in the underground facility

Rooms	Classification
Waste package ramp bottom	Green controlled area
Service ramp bottom	Supervised area
Connecting drifts	Green controlled area
Access drifts	Green controlled area
ILW-LL docking zone	Green controlled area
Handling cells	Red controlled area
ILW-LL disposal cells	Red controlled area
Filtration rooms	Green controlled area
Air return drifts	Supervised area
HLW0 disposal cells	Red controlled area
HLW1/HLW2 disposal cells	Red controlled area
Operating logistics support zone (ZSL)	Supervised area
Hot changing rooms	Supervised area

Initial dose assessment

At the current stage of studies, the preliminary dose assessment helps check that the design of facilities and radiation protection devices ensures that individual doses to personnel do not exceed Andra's target dose of 5 mSv.yr-1. The work stations with the highest doses are those concerned with the reception and preparation of transport containers, and the work stations used for underground facility monitoring. These work stations will be optimised as a priority as part of the ALARA approach, which will be implemented iteratively for the various studies conducted at a later date. It should be noted that, at this stage, the exact location of the equipment to be monitored is not certain and that it is consequently assumed that the equipment in the different rooms is located in the most highly radioactive ambient conditions.

2.1.1.4 Monitoring systems

Monitoring waste packages and equipment

To supplement monitoring of acceptance specifications at producers' facilities, provision is made for dose equivalent rate checks on the transport container and waste packages during unloading, on receipt of each waste package delivered to the surface facilities. In addition, as soon as they are received, transport containers, and subsequently primary packages or disposal packages, undergo removable contamination and dose equivalent rate checks (see Volume II) to ensure compliance.

Statistical checks will also be performed by sampling from the flows of waste packages delivered. The parameters concerned by these checks will include dose equivalent rate, surface contamination, external appearance of the container and gripping arrangements, container integrity, type and quality of materials ensuring containment, and type of radioactive waste, etc.

Individual monitoring

In supervised areas, the personnel are equipped with passive dosimetry devices, at least, and in controlled areas, with active dosimetry devices in addition

Depending on the risk of exposure during operations, in particular for maintenance (e.g. on equipment in surface facility cells with no waste packages present, etc.), the personnel may be equipped with "small radiation protection equipment" such as radiation meters (gamma or neutron depending on the risk) or contamination meters.

At nuclear waste zone exits (zone with a risk of contamination), hand/foot type contamination monitors or survey meters with a sensor are used to check for bodily contamination on operating personnel. In addition, at regulated area exits, the personnel will pass under an overhead detection device to check for bodily contamination before they enter the hot changing room.

Collective monitoring

Collective monitoring of exposure to ionising radiation is carried out by:

- continuous filter monitors for monitoring alpha and beta aerosols in the air in the front and rear zones of cells which may present a risk of contamination in hot workshops and the potentially radioactive waste processing room;
- monitors for tritium, carbon-14 and rare gas monitoring in rooms containing waste packages emitting these radionuclides;
- very high flux gamma sensors for monitoring gamma radiation in shielded cells and handling cells;
- total gamma count water monitor for continuously monitoring the radioactivity of the potentially contaminated effluents collected.

Systems used to monitor ambient conditions (dose rate and air contamination) are connected to alarms (visual, audible) to protect personnel against abnormal operating conditions.

Radiation monitoring panels (TCR) will be used to centralise the measurement data required for facility safety and radiation monitoring.

2.1.1.5 Mitigation measures

At the current stage of studies, the main mitigation measures regarding external and internal exposure are:

- equipment used in incident or accident conditions is designed to avoid the need for operators or emergency personnel to enter rooms where exposure exceeds regulatory thresholds (e.g. remotely-activated fire extinguishing system);
- whenever possible, the motors and electrical cabinets of surface facility shielded cells, docking facades and handling cells in the underground facility shall be located outside the rooms to enable maintenance to be performed behind radiation shielding;
- the design of the radiation protection devices in relation to internal and external hazards;
- removal of radiological source terms during operations;
- use of remote-controlled or robotic equipment to remove source terms or release mechanisms to allow their removal by other means (cranes, etc.);
- use of dosimeters with alarms to prevent personnel from entering areas where conditions are hazardous;
- the design of rooms and equipment (nuclear ventilation systems) that perform a containment function against the risks of internal and external hazards;
- if necessary, use of breathing apparatus for personnel checking the radiological status of potentially contaminated cells, and ventilated suits in the event of a contamination incident.

In order to prevent any excessive exposure of personnel, further provisions are made:

- personnel are equipped with work clothing that is appropriate for the room where they are working;
- personnel must undergo regular medical checks;
- if operator or equipment contamination is suspected or detected, the personnel call in the Cigeo radiation protection department which can respond within minutes;
- if dissemination of radioactive materials is suspected or detected, the radiation protection department carries out radiological mapping of the room and can, if necessary, have contaminated equipment or rooms decontaminated.

2.1.2 Dispersion of radioactive substances

2.1.2.1 Source of risk

The risk of dispersion of radioactive substances in Cigeo facilities is related to the possible migration of the radioactive substances (particles and aerosols) of waste packages during procedures involving the receiving, handling, conditioning, transfer, emplacement or removal of these waste packages, as part of the operating scenarios defined in the Retrievability Options Report (DORec).

In normal operation, the risk of dispersion of radioactive substances is mainly due to:

- Surface removable contamination potentially present on the external surfaces of primary packages and disposal packages limited to 4 Bq/cm² in $\beta\,\gamma$ radionuclides and 0.4 Bq/cm² in α radionuclides
- solid operating waste and aqueous liquid effluents that may have been in contact with contaminated packages.

Table 2.1- shows the location of radioactive substances in Cigeo facilities.

Under incident or accident conditions, risks of dispersion are associated with either an intrinsic failure of the waste packages (e.g. ageing, anomaly detected on arrival), or an internal or external hazard (e.g. dropping, fire, earthquake, etc.) likely to release at least the removable external surface contamination on waste packages, and possibly damage the containment barriers of the primary packages and/or disposal packages, then lead to the release of the radioactivity present inside the packages. The provisions made for controlling non-nuclear risks of internal or external origin that might generate a risk of dispersion are described in the chapters dedicated to each of the risks in this volume.

The other incident or accident conditions concern the release of radioactive substances deposited on the surfaces of the transit zones or transfer equipment, as well as operating waste and effluents that may be generated by maintenance or decontamination work on rooms and equipment.

Table 2.1-7 Location of radioactive substances in Cigeo facilities

	Waste packages	Equipment	Operating waste	Effluents
Surface nuclear processing facility				
Areas 1/2/3 for receiving and preparing transport containers up to docking at the cells.	CP and CS-P in B-type and A-type transport containers	B-type and A-type transport containers	Swab bin Disposable suits, gloves	-
Transport container processing room	CP and CS-P in B-type and A-type transport containers	B-type and A-type transport containers	Swab bin Gloves, disposable suits, overboots, cartridges	Decontamination of surface of unprepared transport container
Unloading, inspection and loading cells for CP/CS-P and unprepared disposal packages (CSs)	CPs, unprepared CSs and CS-Ps	Cell walls Equipment	Equipment maintenance	Cell decontamination [54]
Unprepared CSs buffer zone	Unprepared CSs	Equipment cell walls	Equipment maintenance	Cell decontamination
Cells for conditioning in CSs	CS	Equipment cell walls	Equipment maintenance	Cell decontamination
CS buffer zone	CS	Equipment cell walls	Equipment maintenance	Cell decontamination
Deconditioning cell	Unprepared CSs and CSs	Equipment cell walls	Equipment maintenance	Cell decontamination
CS cask loading cell	Complete CSs	Equipment cell walls	Equipment maintenance	Cell decontamination
Cask storage area and waste package ramp head	CSs and CS-Ps in ILW-LL and HLW cask	Cask walls	Cask maintenance	Cask decontamination
HEPA cell filtration rooms	-	HEPA filters	Disposable suits …	-
Front zone, upper airlocks, hot workshops and stores	-	Equipment room walls	Equipment maintenance	Room decontamination
Operating waste processing	-	-	Operating waste	-
Active and potentially radioactive effluent buffer tanks	-	-	-	Active and potentially radioactive effluents
Underground nuclear facility				
Ramp and connecting drifts and access drifts	CSs and CS-Ps in ILW-LL and HLW cask	Cask walls	-	-
ILW-LL disposal cells and handling cells	ILW-LL CS and CS-P	Equipment cell walls	Equipment maintenance	Equipment decontamination
HLW cell	HLW CS	-	-	-
ILW-LL disposal cell HEPA filtration rooms	-	HEPA filters	Disposable suits	-
ZSL operating waste processing	-	-	Operating waste	-
Buffer tanks for potentially radioactive effluents	-	-	-	Potentially radioactive effluents[55]

[54] Decontamination of cells, rooms or casks remains occasional and will be subject to scheduling, at intervals to be specified in the general operating rules.
[55] : Potentially radioactive effluents coming from water seepage from ramps, drifts and HLW disposal cells.

2.1.2.2 Chosen containment options

The (primary and disposal) packages, facilities and operating processes are designed to ensure that contamination levels remain as low as possible in the rooms of the facility, and to limit the release of radioactive materials outside the facility in order to safeguard the personnel, public and environment during all identified operating conditions during the facility operating phase.

The risk of dispersion is controlled by placing various containment barriers between the environment and the radioactive materials (in accordance with Article 3.4 of the Order of 7 February 2012 (16). The objective for the Cigeo facilities is to:

- set up two independent containment barriers (static and/or dynamic) for normal operating conditions;
- maintain at least one permanent (static and/or dynamic) containment barrier in place for incident and accident operating conditions.

These barriers are divided into containment systems.

The safety guide for the final disposal of radioactive waste in a deep geological formation (17) adopts the following provisions: "The (disposal) package shall have the ability to contain harmful substances, as appropriate to the type of waste contained and given the environment in which it is located. In order to meet this objective, it is recommended that the package:

- prevents the dissemination of radioactivity into other components of the disposal system for a given period after emplacement in the facility.
  - ✓ For waste with high specific activity and spent fuel, this containment shall be ensured in particular for a period at the end of which the contact temperature of the packages shall be low enough for any releases to occur under known conditions.
  - ✓ For waste packages with an intermediate level of radioactivity, this containment concerns non-gaseous radioactive materials. It shall be ensured at least through the operating phase".

2.1.2.3 Primary containment system

The waste will be received at Cigeo in the form of primary packages (CP) and in some cases, primary packages already placed in a disposal container by the producers (CS-P). The waste is disposed of in a cell as a disposal package (CS). This consists of one or more primary packages placed in a disposal container. Direct disposal of ILW-LL primary packages is also possible.

<u>HLW</u>

For HLW packages, the primary containment system is ensured:

- by the primary package before emplacement in a disposal container. This primary containment barrier is effective in normal operation, throughout operation and for the incident and accident operating conditions identified in the Cigeo surface facilities before emplacement in the disposal container;
- by two containment barriers after emplacement in the disposal container:
  - ✓ primary package;
  - ✓ steel disposal container. This barrier is effective for all operating conditions and in the surface facilities, during transfer to the disposal cells, after emplacement in the HLW disposal cells, and when removing the packages.

<u>ILW-LL</u>

For ILW-LL primary packages intended for disposal without a disposal container, primary containment is ensured by the primary package alone, from the time it is received at the surface facility up to its emplacement in the disposal cell.

For ILW-LL primary packages intended for disposal in a disposal container:

- primary containment is ensured by the primary package alone before the package is placed in the disposal container;
- primary containment is ensured by the disposal package once the package is placed in the disposal container.

As emplacement operations are completed rapidly, the primary package alone is sufficient to ensure primary containment pending emplacement in the disposal cell.

Inside the disposal cell (see Section 2.7.1), the disposal container may be required to act as a containment barrier to overcome any defects in certain primary packages while Cigeo is in its operating phase. When this function is assigned to the disposal container, an additional containment system will be required for the disposal package, namely a sealed disposal container with or without immobilisation of the primary package. This is referred to as "enhanced containment capability".

At this stage of the studies, three possible disposal solutions are therefore considered for the various types of ILW-LL package to be delivered to Cigeo for safe disposal:

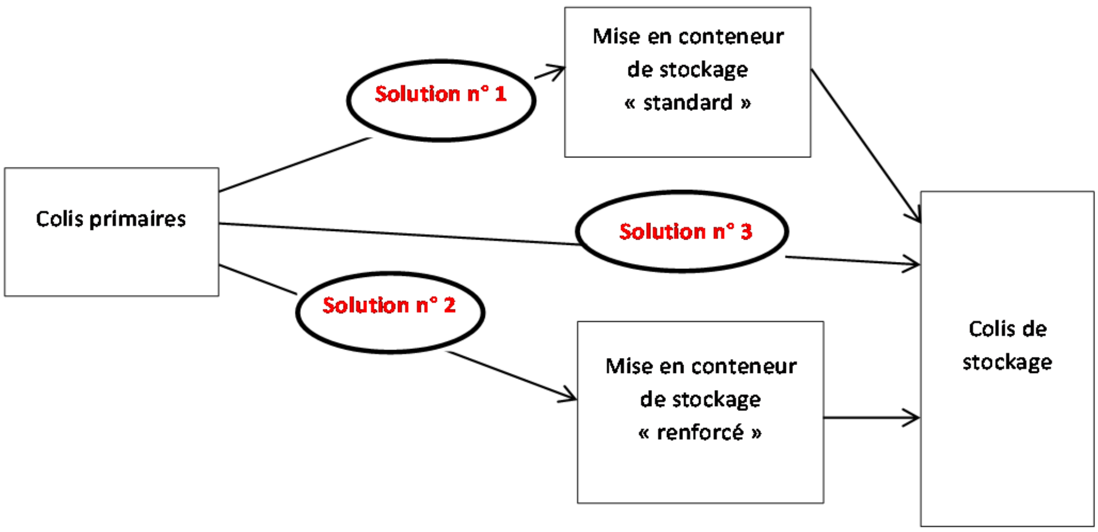

Figure 2.1-1 Solutions regarding the composition of ILW-LL disposal packages

- <u>solution 1: primary packages placed in a "standard" disposal container (screwed shut</u>). ILW-LL packages as conditioned and delivered to Cigeo by the producer are in the form of primary packages. On arrival at the Cigeo surface facility, one or more primary packages are placed in a disposal container to form a disposal package, ready to be transferred and placed in the disposal cells. The primary packages will confine aerosols throughout the operating phase in normal operation and in degraded mode. The ILW-LL disposal container will not ensure containment but withstands certain hazards, such as falls or fires, and retains any radioactive substances that might be resuspended if these hazards were to occur (at this stage, a retention factor of 10^{-2} is applied for a fall from less than the container qualification height, i.e. 2.3 m);
- <u>solution 2: primary packages placed in a disposal container "with enhanced containment capability"</u>. The packages delivered to Cigeo by the producer come as primary packages that are designed to ensure containment at the time of their arrival, but not for the entire duration of the facility operating phase. On arrival, the primary packages are placed in a disposal container designed to guarantee the containment of aerosols for the entire duration of the operating phase in normal operation and in degraded mode. The unit formed by the primary packages and the disposal container ensures that aerosols are confined throughout the operating phase in normal operation and in degraded mode. The disposal container "with enhanced containment capability" is designed to withstand the same hazards as the "standard" container and therefore retains any radioactive substances that might be resuspended if these hazards were to occur (at this stage, a

retention factor of 10^{-2} is applied for a fall from less than the container qualification height, i.e. 2.3 m);

- <u>solution 3: direct disposal of primary packages</u>. The waste packages of the type conditioned and delivered to Cigeo by the producer come as primary packages. These are disposed of as they are, without being placed in a disposal container, and are then considered as disposal packages. They must therefore ensure aerosols are confined throughout the operating phase in normal operation and in degraded mode. They must also withstand hazards such as falls and fire to guarantee compatibility with facility design provisions adopted to ensure containment of non-gaseous radioactive materials under incident and accident operating conditions throughout the operating phase.

Table 2.1-8 Primary containment system adopted for ILW-LL disposal packages according to disposal solution and life phase

<table>
<tr><th></th><th>CP in "standard" CtS</th><th>CP in "enhanced" CtS</th><th>CP for direct disposal</th></tr>
<tr><td>Disposal cell emplacement operations</td><td rowspan="3">One containment barrier: primary package

The CtS helps to protect the primary package and to retain radioactive substances in accident conditions</td><td>Two containment barriers: primary package + disposal container</td><td rowspan="3">One containment barrier: primary package</td></tr>
<tr><td>Disposal in tunnel (throughout operating phase)</td><td>One containment barrier: disposal container</td></tr>
<tr><td>Removal from operation (period of one year after disposal)</td><td>Two containment barriers: primary package + disposal container</td></tr>
</table>

For liquid effluents that are contaminated (active effluents) or likely to be (potentially radioactive effluents), the primary static containment system consists of the tanks and systems in which they are collected.

2.1.2.4 Secondary containment system

A secondary containment system is implemented to maintain the integrity of at least one of the two systems in incident/accident conditions. It limits the release of radioactive substances to adjacent rooms and the environment in the event of loss of the primary containment system.

The secondary containment system is composed of static and, where applicable, dynamic barriers according to the zones of the facility and the processes involved.

Dynamic containment is designed to overcome any leakage from the static containment formed by the walls of the volumes in question. It is ensured by the ventilation system, which fulfils two functions:

- managing pressure levels to ensure that air flows from volumes with a low potential risk of radioactive contamination towards those with a high potential risk of radioactive contamination. Dynamic containment also serves to confine, process and monitor contamination as close as possible to the source and to back up the other provisions made for protecting workers against ionising radiation;
- maintaining a significant level of negative pressure inside controlled areas with a potential risk of radioactive contamination, to prevent uncontrolled release outside the plant and to ensure that gaseous effluents converge on identified release points and, if necessary, to allow effluent purification and monitoring to be carried out.

<u>HLW</u>

Secondary containment, consisting of the civil works of the rooms associated with a nuclear ventilation system (dynamic containment), is ensured until the primary packages are placed in the disposal containers.

After conditioning in disposal packages and inspection, a single containment system composed of two containment barriers is sufficient to ensure containment during the transfer of packages to the disposal cells, and in the HLW micro-tunnels, whatever the conditions and with no need for a second containment system.

The solutions considered for transfer (low speed) and emplacement of disposal packages (limited handling height, reduced fire load of equipment, etc.) are aimed at limiting potential hazards concerning the package. Between now and the construction licence application, a check will be carried out to ensure that HLW disposal packages are in effect designed to withstand the various hazards.

<u>ILW-LL</u>

Note: with regard to the planned (solution 2) or conceivable disposal solutions for which the primary containment system may be composed of two containment barriers (primary package and disposal container fulfilling a containment function), the need for a secondary containment system must be analysed. This analysis must take into account the operating conditions and potential common failure mode risks between the different barriers of the primary containment system, in accordance with the INB Order.

- Surface facility

In the surface facilities, provision is made for a secondary containment system in the various rooms through which the ILW-LL packages pass before being placed in the cask. This consists of a containment barrier ensured by the civil works of the rooms, as well as nuclear ventilation (dynamic containment). The secondary containment system is effective particularly in the incident and accident operating conditions identified in the surface facilities.

The surface facility ventilation systems consist of:

- a conventional system to ventilate rooms outside the controlled area (technical rooms);
- an I-C1 system to ventilate controlled areas that are free of any nuclear substances or those in which these substances are conditioned in containers designed to withstand hazards and, under incident or accident conditions, do not lead to a risk of these radioactive substances being dispersed (transport containers, casks);
- an IIA-C2 system, with an air supply shared with that of the cells, to ventilate controlled areas that are free of any nuclear substances but may communicate with the cells (front zones) at some points;
- an IIB-C3 or IIIB-C4** system, with the air supply shared with the above, to ventilate controlled areas that contain nuclear substances conditioned in containers and for which hazards could, under incident or accident conditions, lead to a risk of dispersion of these radioactive substances.

At the current stage of studies, the cell used for unloading primary packages from transport containers, namely C5 inspection and disposal container loading, would require this classification.

The design of the ventilation systems and their electrical power supply, particularly in terms of equipment redundancy and hazard design, is adapted to the consequences for facility safety. These systems include two air supply and extraction fans (see Figure 3.3-34). In the event of loss of the normal electrical power supply or of a fan, the process stops and the facility is brought to a safe state. The need for air supply and extraction redundancy for IIB-C3 to IIIB-C4** systems (only concerned with accident conditions) will be studied between now and the construction licence application.

The infrastructure of the surface facilities (cells and buildings) is designed to remain stable under earthquake conditions and takes into account hazard scenarios, particularly fire and falling heavy loads.

Once the disposal package is placed in the cask, the cask forms the secondary containment system. It is described in the section on the underground facility.

- Surface-bottom connection and underground facility

The secondary containment system adopted during ILW-LL package transfer via the ramp and drifts, consists of a containment barrier provided by the transfer cask.

Cask performance in terms of containment is ensured by a stainless steel container in the internal wall of the cask body and by its door. A set of seals between the door and its frame allow leak tests to be performed. Thermal insulation provides fire protection for the seals. The rigid structure of the cask provides protection against falls, impacts or collisions.

On docking at the cask loading or handling cells, static containment is ensured between the docking facade door and the cask door. In the event of static containment failure, dynamic containment is ensured by the negative pressure between the two rooms and a calibrated clearance around the edge of the docking zone.

Cask performance meets ramp, connecting drift and access drift operating objectives in containment class C1. At this stage of the studies, a normalised leak rate of 1.3×10^{-3} $Pa.m^3/s$ is applied.

ILW-LL casks are designed to fulfil their secondary containment function, regardless of the hazard scenarios considered in their design (falls, impacts, collisions, fires, earthquakes, etc.) and to protect the disposal package that they contain from all mechanical and thermal hazards that might lead to degradation of its containment function (see Figure 3.3-21).

- ILW-LL disposal cells and ILW-LL disposal cell filtration rooms

In ILW-LL disposal cells and ILW-LL disposal cell filtration rooms, the selected secondary containment system consists of a containment barrier provided by the civil works of the tunnel, combined with nuclear ventilation (dynamic containment). This secondary containment system must be effective, particularly under the incident and accident operating conditions identified in ILW-LL disposal cells, whether for disposal package emplacement or removal operations.

This choice of secondary containment system is based on the performance considered at this stage for the primary containment system consisting of the ILW-LL disposal package, as follows:

- the normal operating range of the disposal cell considers:
  - ✓ possible release of radioactive gases;
  - ✓ no dispersion of radioactive aerosols contained in the primary packages. The level of removable surface contamination of the disposal packages does not exceed 4 Bq/cm² for βγ radionuclides and 0.4 Bq/cm² for α radionuclides. The degradation of a limited number of packages leading to the presence of airborne particles in the disposal cell is nevertheless taken into consideration. Given the requirements specified for primary packages and disposal containers, and the relatively mild environmental conditions, this number and the extent of degradation will remain very limited, to ensure compliance with the containment class targeted in ventilation design;
- in the event of an accident during emplacement or removal of disposal packages into or from the disposal cell, the secondary containment system is designed to collect any airborne substances resulting from the accident and to enable the tunnel to be purified.

In order to meet these principles and given package performance, the option adopted is a ventilation system for handling cells and disposal cells consisting of an IIA-C2 system.

The general ventilation of the underground facility and, therefore, of the ILW-LL disposal cells is "longitudinal", with a fresh air sweep of underground drift standard sections. In the ILW-LL zone, air return is ensured by a ventilation duct located in a dedicated drift. The main ventilation units are installed at the shaft and ramp heads at the surface.

The ventilation system is designed with redundant air supply and extraction functions. In the event of loss of the normal electrical power supply, the power supply to the extractors of operating zone exhaust air extractors, ILW-LL cell filtration units, and last filtration stage rooms, and to the sensors at the ILW-LL cell exit, switches to emergency generators located at the surface.

The civil works of the disposal cell and the ventilation system are designed to withstand potential hazards (in particular collision, earthquake, rising temperatures, etc.).

2.1.2.5 Monitoring systems

<u>Monitoring the primary containment system</u>

In addition to the monitoring carried out by Andra on producers' facilities, in-line inspections of waste packages are set up during the various operations carried out in the surface facility (see Volume II Section 4.5).

In particular, waste packages must meet the contamination limit defined in the acceptance specifications. In order to monitor this criterion and detect non-compliance as soon as possible, inspection operations are integrated into the process during transport container unloading, when placing primary packages in disposal packages, and before cask loading.

Monitoring is also carried out on HLW and ILW-LL packages that are placed in instrumented observation cells, and that reproduce hydrological, thermal, mechanical and, as far as possible, radiological conditions similar to those encountered in the disposal cells and tunnels.

In the underground facility, the contamination level in the ILW-LL disposal cell is monitored by a device installed at the exit of each disposal cell.

Liquid effluent collection channels and tanks are equipped with a liquid presence detector at the lowest points. The tanks are also equipped with a continuous level monitoring system and level alarms (thresholds to be defined).

Monitoring ambient conditions

All the surface facility rooms where primary packages and disposal packages transit or are disposed of are ventilated.

ILW-LL disposal cell ventilation ensures, in particular, that ambient temperature and humidity conditions limit phenomena liable to deteriorate disposal packages.

HLW disposal cells are not ventilated. The causes of damage to HLW disposal packages are associated with corrosion phenomena. Their design prevents water flowing onto waste during its thermal period, which extends far beyond the operating period.

Monitoring ambient contamination

In general, ambient contamination will be constantly monitored throughout the surface and underground facilities. The following provisions are planned:

- monitoring atmospheric contamination in rooms at the surface that contain waste packages on a temporary or permanent basis (unloading cells, waste package inspection cells, conditioning/deconditioning cells, non-compliance processing cells, buffer zones, active and potentially radioactive effluent storage rooms);
- monitoring atmospheric contamination in working zones (front and rear zones of cells, hot workshops, rooms for the last filtration stage for ILW-LL disposal cells during filter replacement operations, operating waste buffer zones) and personnel movement zones (aerosol monitors placed close to entry/exit airlocks to check that contamination does not spread to areas where personnel are not wearing personal protective equipment (PPE));
- monitoring atmospheric contamination in handling cells, in the operating ZSL waste package buffer room and in ILW-LL disposal cells;
- monitoring the activity of collected liquid effluents.

Radiological monitoring equipment is installed to monitor activity concentrations in the underground facility. This includes:

- fixed monitors for monitoring atmospheric contamination (aerosols) in rooms with a risk of incident-related contamination. These take samples directly from the rooms or the ventilation extraction ducts to monitor all rooms with large volumes and where no particular work stations are located. The rooms included are all those where primary packages and disposal packages transit and are placed;
- atmospheric dust sampling equipment (APAs) installed for off-line monitoring. This equipment is installed in handling cells and the last filtration stage rooms of ILW-LL disposal cells.

Monitoring radiological cleanliness

Inspections and measurements of surface contamination in the different rooms are carried out for the purpose of contamination mapping. Rooms with additional artificial radioactivity are referred to as "contaminated" and appropriate signage is installed at their entrances. Decontamination is performed to return to the situation defined for zoning purposes.

Rooms, equipment, small tools and personnel are systematically screened for contamination before and after each operation in regulated areas.

Personnel leaving controlled areas (mainly the handling cells in the underground facility) for supervised areas must pass through a hand and foot contamination monitor and/or contamination meter. Screening for surface contamination on tools or equipment is performed by personnel using smear test swabs and measurements using α or $\beta\gamma$ sensors or contamination meters.

Personnel exiting controlled areas pass through a portal monitor. Radiological smear tests on equipment are performed in a dedicated airlock. Smear counts are carried out on a measuring bench.

Monitoring the secondary containment system

Monitoring ventilation systems ensuring dynamic containment includes:

- monitoring the main ventilation parameters (negative pressure according to the containment class of the room, pressure differential between rooms with different classifications, air flow rates to ensure dynamic containment and compliance with negative pressure cascades, air flow rates to ensure dilution and turbulent flow to guarantee that the LEL threshold is not reached in the presence of hydrogen, air flow rates to remove the energy released by waste packages or equipment operation, to ensure that ventilation systems meet criteria such as maximum allowable temperature or power consumption, etc.);
- monitoring ambient conditions of rooms using atmospheric radiation protection monitors;
- regularly checking the effectiveness of HEPA filters.

In order to limit the frequency of HEPA filter replacement in ILW-LL disposal cells due to the release of dust from disposal package concrete and disposal cell structural concrete, HE filters may be inserted before the HEPA filters (solution currently still under study).

The ILW-LL cask containment is monitored by inspections (checking inter-seal pressure, internal contamination density, checking cask surface contamination).

In the position for docking to a cell, static containment is extended to the internal cavity of the cask and supplemented by the dynamic containment of the cell. Containment is monitored by checking the pressure in the inflatable confinement seals and by continuously monitoring negative pressures between rooms before and during docking.

Release monitoring

Radiological monitoring of the environment is carried out in two phases: liquid and gaseous radioactive release monitoring at release points, and monitoring the impact of these releases over time. The purpose of release monitoring is to ensure compliance with the authorisation limits defined for the INB and to prevent any abnormal situation.

Monitoring on and around the site will be organised in order to:

- carry out continuous measurement of potential atmospheric releases at the ventilation stacks, and in the shaft zone and ramp zone (gas, dust and aerosols);
- check liquid effluents collected in basins before release;
- monitor radioactivity of groundwater at surface sites;
- perform environmental monitoring around the site.

After radiological inspection, liquid effluents (mainly drainage water) flow into the river through discharge channels. Any radioactive effluents are stored in a tank and sent to a processing facility in a tanker truck.

Gaseous effluents are channelled and released into the atmosphere. They are monitored continuously (in real time and/or after the event) at the various outlets in the shaft zone and ramp zone.

2.1.2.6 Mitigation measures

The robustness required of HLW packages and the associated design requirements preclude any degradation of the containment function performed by the primary packages and disposal packages during disposal operations, or in the disposal cell once the waste package has been disposed of, and for as long as the disposal facility is in operation.

Concerning ILW-LL packages, in the event of failure or deterioration of the primary containment function performed by the waste package, a secondary containment system (cell walls or doors, ILW-LL casks, disposal cell (and extension) walls, nuclear ventilation) mitigates any impact. Since the secondary containment system is mainly composed of passive static elements (ILW-LL transfer casks and disposal cell infrastructure), the main hazards likely to degrade them are related to handling, fires and earthquakes. Specific provisions are put in place in relation to these risks:

- the ILW-LL casks continue to fulfil their secondary containment function regardless of the hazard scenarios considered in their design (falls, impacts, collisions, fires, earthquakes, etc.) and protect the disposal package that they contain from any mechanical and thermal hazards liable to impair its containment properties;
- facility infrastructure design takes hazard scenarios into account, particularly earthquakes, fires and falling of heavy loads.

Concerning the ventilation systems for cells and disposal cells, the design of the ventilation systems and their electrical power supply, particularly in terms of equipment redundancy and hazard design, is adapted to the consequences for facility safety.

2.1.3 **Criticality**

2.1.3.1 Source of risk

The criticality hazard is the risk of occurrence of a divergent fission chain reaction within a fissile medium.

The mean mass of fissile materials (uranium and plutonium) in most waste packages is relatively limited (a few tens of grams). Note that the primary waste packages received at the facility are designed and produced to be safe in terms of criticality, whether on their own or in storage conditions at producers' sites.

2.1.3.2 Objectives

The purpose of this analysis is to identify the main safety provisions associated with the criticality hazard (for design and/or operation) with a view to the deep geological disposal of the disposal packages.

2.1.3.3 Criticality safety principles

The general provisions concerning the control of nuclear chain reactions in Cigeo are defined in accordance with the Order of 20 November 2014 approving decision no. 2014-DC-0417 of the French Nuclear Safety Authority on 7 October 2014, on control of the criticality hazard in basic nuclear installations.

As part of the construction licence application, this facility will undergo detailed analysis to ensure that the criticality hazard is controlled in the normal and abnormal configurations considered, taking into account the implemented processes.

In accordance with the defence-in-depth principle, equipment or organisational and human provisions are defined and implemented for prevention of the criticality hazard, monitoring the facility to detect any discrepancy likely to compromise risk control and to mitigate the consequences in the event of a criticality accident.

Under a prudent design approach, the following principle is applied:

- a criticality accident must not, under any circumstances, occur as the result of a single anomaly;
- if a criticality accident can result from the concomitant appearance of two anomalies, it is therefore demonstrated that:
  - ✓ the two anomalies are independent;
  - ✓ the probability of occurrence of each of the two anomalies is sufficiently low;
  - ✓ each anomaly is found using appropriate and reliable means, allowing for repair or implementation of remedial measures within an appropriate period.

In the case where this principle cannot be applied, technical and organisational provisions are implemented to make the accident scenarios concerned extremely improbable, with a high degree of confidence.

In particular, a design accident situation must not lead to a criticality hazard.

2.1.3.4 Assumptions associated with the process

The transport containers are unloaded dry in the Cigeo facility vertically or horizontally. The primary package(s) is/are then inspected then inserted into a disposal container (containing 1, 2 or 4 primary package(s)).

The disposal package (disposal container containing the primary package(s)) is loaded singly into a transfer cask before being routed to the disposal cell.

At this stage, the analysis considers a breakdown into functional units, each forming a "criticality unit", corresponding to the stages of the Cigeo facility process. The facility process is summarised in Chapter 1 of this Volume.

2.1.3.5 Criticality safety of the Cigeo facility

<u>Reference fissile medium</u>

The fissile materials are of the following type:

- Uranium;
- Plutonium;
- Uranium/Plutonium mixture.

They are in the following physico-chemical forms:

- Metal (U, Pu, U+Pu);
- Oxide (UO_2, PuO_2, $(U+Pu)O_2$) in the form of powder, chips, pellets, etc.

In addition, the fissile materials are present in various isotopic vectors.

At this stage of design, and as part of a conservative approach, the reference fissile medium considered for each family of primary packages is a homogenous mixture of $^{239}Pu_{metal}$ – CH_2.

Taking into account a medium with 100% ^{239}Pu ensures coverage of all the isotopic characteristics of plutonium likely to be encountered, as well as the presence of the ^{235}U isotope. In the context of a method for inspection by mass: the ^{235}U present is then assimilated to ^{239}Pu.

A condition of moderation by CH_2 with density covering moderation by water.

This highly conservative reference fissile medium will be reviewed subsequently for each family of waste packages present at the facility.

Non-fissile environments

The non-fissile environments within the facility Cigeo are taken into account for the criticality safety analysis, from the moment when these materials can significantly affect neutron moderation, reflection and absorption phenomena .

Inspection method

At this stage of design, the inspection method considered focuses on the mass per waste package combined with geometry (packages, cask and/or storage facilities, disposal cells according to configuration).

The acceptability process will serve to ensure that, based on producer statements and evidence, the waste packages received comply with Cigeo acceptance specifications.

Taking in of a new waste package is dependent on compliance with the authorised mass limit.

Other inspection methods will be able to be considered (fissile material content, for example) in the detailed design phase for certain waste package families.

Criticality Limits

The criticality limits are defined such that the effective multiplication factors (keff), including all calculation uncertainties, are lower than 1 with a sufficient margin. An acceptability criterion of 0.95 is to be considered for the normal configurations (normal and degraded) and 0.97 for the abnormal configurations (incident and accident conditions).

Criticality Safety Provisions

▪ ***Normal operation***

In normal operation, the criticality hazard arises mainly from:

- the emplacement of primary and disposal packages in buffer zones;
- package transfer operations;
- emplacement of disposal packages in a disposal cell.

For operations associated with receiving and preparing transport containers, before the containers are unloaded, it is considered that the operating conditions encountered are covered by the transport approval document and compliance with its requirements.

c) Buffer zones

The primary packages and disposal packages are stored in dedicated zones.

As a preliminary step, in the basic engineering design stage (APS), the reactivity was assessed for a store of 40 primary packages in contact and arranged on a single level each containing 200 grams of ^{239}Pu. This configuration has an effective multiplication factor (k_{eff}) lower than 0.90.

Similarly, the reactivity of an infinite network of disposal packages in contact containing primary packages with 200 g of ^{239}Pu was assessed:

- for ILW-LL packages, this configuration has an effective multiplication factor (k_{eff}) lower than 0.90;
- for HLW packages, this configuration has an effective multiplication factor (k_{eff}) equal to 0.92.

Depending on the design of these buffer zones in the detailed design phase (APD), additional assessments associated with the various configurations may be performed.

d) Package transfers

The waste packages are handled throughout the process at the Cigeo facility.

The primary packages and disposal packages are safe by design. Handling disposal packages in a cask is covered by specific calculations taking the geometry of disposal packages and casks into consideration, as well as the specific reflection conditions (addition of thickness of cask steel).

As a preliminary step, in the basic engineering design stage (APS), the reactivity of a full cask was assessed in the most conservative disposal package configuration (200 grams of ^{239}Pu per primary package, 2 primary packages on 2 levels in the disposal package). This configuration has an effective multiplication factor (k_{eff}) equal to 0.93. This configuration complies with the acceptability criterion in normal operation.

e) Disposal cells

The disposal packages are inserted into the disposal cells individually.

In HLW cells, disposal packages are stored one behind another. For unloading, the HLW cask is positioned in the extension of the cell.

In ILW-LL disposal cells, disposal packages are disposed of in different configurations depending on the type of waste package involved and over a length of several hundred metres (see Volume II). The handling cell can only accommodate a single disposal package and is located in alignment with the disposal cell.

As a preliminary step, in the basic engineering design stage (APS), the reactivity of an infinite disposal facility was assessed:

- for ILW-LL packages, the most reactive configuration (200 grams of ^{239}Pu per primary package, 2 primary packages on 2 levels in the disposal package, 2 levels of disposal package in 3 rows) has an effective multiplication factor (k_{eff}) equal to 0.93;
- for HLW packages (infinite line), the most reactive configuration (200 grams of ^{239}Pu per primary package, 2 primary packages in the disposal package) has an effective multiplication factor (k_{eff}) equal to 0.91.

- ***Incident and accident conditions***

f) Risks associated with handling

The scenarios considered that could impact criticality safety are: dropping a single primary package, a disposal package or a transfer cask in a buffer zone.

Single primary package or disposal package or transfer cask

Dropping a single primary package does not compromise the criticality safety of the facility due to the limited quantity of fissile material contained.

Dropping a single disposal package or transfer cask is not likely to cause deformations leading to a significant modification of its geometry.

Consequently, the criticality safety of the facility is not compromised in the event of a single primary package, disposal package or transfer cask being dropped.

Dropping a primary package or disposal package in a buffer zone

The consequences of dropping a primary package or disposal package in a buffer zone have been estimated. This situation does not compromise the criticality safety of the facility.

The composition of the waste (presence of an immobilisation matrix, compacted forms, etc.), allows for elimination of a scenario of grouping together of fissile material.

g) Risks associated with earthquake

An earthquake could cause a primary package, disposal package or transfer casks to be dropped as well as change the layout of the waste packages (buffer zones, cells).

The details given in the paragraph above show that the criticality safety of the facility is guaranteed in the event of a primary package, disposal package and transfer casks being dropped.

Concerning the change of the package layout (buffer zones, cells), the modelling implemented considers the waste packages in contact. This modelling avoids the need to consider storage space between the waste packages.

An earthquake is therefore not likely to compromise the criticality safety of the facility.

h) Risks associated with flooding

Currently, the moderation-based inspection method is not selected, as preliminary assessments take into account the fissile material with optimum moderation.

The reflection conditions considered for the preliminary assessments cover flooding.

It is considered that, from the point of view of the criticality hazard, no special provisions are necessary.

i) Risks associated with fire

A fire could trigger damage likely to modify the properties of materials and, in extreme cases, trigger a deformation of the waste packages.

Concerning the concrete heating phenomenon, an initial assessment on the storage of disposal packages in the surface facility shows that the dehydration of concrete has no significant impact on the reactivity of the storage. With regard to this, from the point of view of the criticality hazard, no special provisions are necessary.

Concerning the phenomenon of deformation in the event of fire, this is not likely to entail a significant change in its geometry. Design provisions can be implemented, such as the level of fire resistance, for example.

2.1.4 Heat

2.1.4.1 Source of risk

The heat released from the ILW-LL and HLW packages is associated with the radioactive materials contained in these waste packages which emit radiation, leading to production of heat. The HLW packages release more heat than the ILW-LL packages (see Volume II Section 1.6.3: Design-basis characteristics).

The potential risks associated with a major heat release are:

- degradation of the properties of the waste and/or its matrix;
- degradation of the concrete forming the ILW-LL disposal containers and the concrete of the walls of the rooms containing waste packages;
- degradation of materials forming items of equipment such as the neutron shielding of casks:
- degradation of clay rock performance ;
- failure of electronic equipment;
- hazardous working conditions for personnel, potentially causing burns in contact with hot walls, for example.

The rooms and equipment containing waste packages and materials and equipment sensitive to a risk of heat release in the Cigeo facilities are shown in the Table 2.1- below.

Table 2.1-9 Location of zones at thermal risk in the Cigeo facilities

Zone	Waste packages	Room, equipment or environment
Surface nuclear installation		
Receiving and preparing areas up to docking at cells	CP and CS-P	B-type (passive cooling) or A-type (non-thermal) transport containers
ET-V unloading cells	CP and CS-P	Cells (walls, ports, penetrations) process-sensitive equipment
ET-H unloading cells	CP and CS-P	Cells (walls, ports, openings) process-sensitive equipment
Unprepared CS and CP/CS-P buffer zones	CPs, unprepared CSs and CS-Ps	Cells (walls, ports, openings) process-sensitive equipment
Complete CS and CS-P buffer zones	Complete CSs and CS-P	Cells (walls, ports, openings) process-sensitive equipment
Underground nuclear disposal facility		
Cask storage area, ramp and drifts	CS and CS-P during transfer	ILW-LL and HLW transfer casks
ILW-LL, HA0 and HLW1/HLW2 drifts	CS and CS-P disposed of in cell	Process-sensitive equipment
ILW-LL disposal cells and handling cells	CS and CS-P	Cells and disposal cells/tunnels (walls, openings) process-sensitive equipment
HLW0 disposal cells	CS and CS-P	HLW cells (walls, openings) process-sensitive equipment
HLW1/HLW2 cells	CS and CS-P	HLW cells (walls, openings) process-sensitive equipment

2.1.4.2 Safety requirements

In accordance with the Safety Baseline adopted in Cigeo design for the operating phase (22), the fire baseline for Cigeo design (31) and the requirements imposed for design at the basic engineering design stage (APS), certain temperature criteria are to be met to demonstrate the safety of Cigeo.

The objectives to be met under normal conditions are as follows:

- the temperature of hot walls accessible to personnel must be limited to 50°C;
- the ambient temperature of the air in the rooms containing sensitive equipment providing or monitoring safety functions must not exceed 50°C (or lower temperatures to take account of their operating range);
- maintaining the mechanical properties of concretes requires a temperature kept below 65°C under normal (continuous) operating conditions;
- the temperature threshold, not to be exceeded for ILW-LL primary packages of bituminised waste is 30°C under normal operating conditions (continuous operation);
- the limit temperature threshold, not to be exceeded for waste packages of cold vitrified waste (ILW-LL6) under normal conditions is 50°C;
- the acceptable limit temperature for HLW primary packages is 450°C at the core of the glass under normal operating conditions;
- the limit temperature to be respected for clay rock protection is 90°C.

The objectives to be satisfied under incident/accident conditions are:

- Maintaining the mechanical properties of concretes requires the temperature to be maintained below 80°C under incident conditions;
- The limit temperature threshold, not to be exceeded for the ILW-LL primary packages of bituminised waste is 50°C under incident conditions and 0°C under fire conditions;
- The acceptable limit temperature for the HLW primary packages is 500°C under incident/accident conditions;

2.1.4.3 Preliminary assessments of the thermal risk associated with the waste packages

In the surface facilities, the preliminary assessments performed in the various rooms of the facility with pessimistic assumptions show that the temperature criteria shown in the previous section are not reached in the absence of ventilation.

The main assumptions taken into account for performance of these preliminary assessments are:

- The thermal values for the disposal packages of 100 W/CS for the ILW-LL packages and 500 W/CS for the HLW packages;
- The rooms are considered filled to their maximum capacity by the waste packages;
- The external temperature considered is the extreme hot temperature in continuous operating mode of +35°C. This temperature is also considered as the ambient temperature of the rooms adjacent to the buffer zones in the event of the ventilation stopping;
- In an initial approach, the contributions other than those of the waste packages are ignored (lighting, equipment) in favour of the heat released by the waste packages;
- The ventilation is stopped in the rooms concerned and in the adjacent rooms.

No specific provision is necessary, therefore, in the rooms of the surface facilities to ensure the control of the risks associated with the heat released by the waste packages.

in the underground facility, taking account of the current theoretical spacing between cells and the layout of the waste packages within the cells, the preliminary assessments show that the temperature criteria are not reached.

The preliminary assessments performed concern:

- HLW0 and HLW1/HLW2 disposal cells for which the calculations show that the 90°C criterion for clay rock is not reached;
- ILW-LL disposal cells which, according to the calculations performed, meet temperature criteria, without taking ventilation into account. The assessments take into account values of 15 W/CP and of 60 W/CS.

During the transfer of packages, the consequences of an increase in the cask temperature have been assessed with regard to the bounding heat values for the packages transported. The pessimistic assumption considered at this stage is an absence of heat exchanges of the cask with ambient conditions (adiabatic). The criteria analysed relate to the sensitivity of the neutron shielding of the HLW casks and the criteria relating to the ILW-LL packages. This preliminary assessment shows that the maximum transfer period must be less than one month to prevent the deterioration of the neutron shielding and less than 1.5 months to prevent degradation of a component of ILW-LL. These periods are compatible with the implementation of measures to reach a safe state.

2.1.4.4 Preventive measures

The current preventive measures for controlling the thermal risk are:

- the knowledge and limitation of the heat rating of the packages received at the disposal site;
- compliance with the design and materials used for the disposal packages and for the rooms containing the waste packages and their equipment;
- the design of the cells that allows the removal of heat released by HLW and ILW-LL packages by passive conduction in the Callovo-Oxfordian formation, from the time of disposal to the closure of the disposal cells;
- compliance with the layout and number of waste packages placed in the disposal cells;
- setting up of a procedure to limit the time of presence of waste packages in the transfer casks in the event of immobilisation of the casks.

2.1.4.5 Monitoring systems

Monitoring of waste packages

In addition to the monitoring performed upstream by Andra on the producer facilities, the waste package acceptance process in particular concerning the maximum allowable load forms part of the monitoring provisions.

Statistical checks will also be performed by sampling from the flow of waste packages delivered.

Monitoring of the rooms of the nuclear facilities

Certain rooms containing waste packages are equipped with sensors for ambient temperature monitoring. Thermal probes are therefore used to monitor the temperature and indicate any changes.

2.1.4.6 Provisions for mitigation

Mitigation measures are mainly concerned with the ventilation implemented in different rooms to control risks other than the thermal risk, while allowing removal of heat from the waste packages.

In the event of the equipment used to transfer casks containing waste packages being shut down, its design allows the cask to be put down and then picked up again by another item of equipment to complete the operating cycle and the removal of the waste package from the cask.

2.1.5 **Radiolysis of waste**

2.1.5.1 Source of risk

Concerning HLW, the primary packages are gastight. In addition, the disposal container is welded closed and leaktight. Therefore, there is no risk associated with HLW package radiolysis.

The risk associated with waste radiolysis is due to the presence of hydrogenated materials contained in ILW-LL packages that can produce radiolysis gases via the effect of ionising radiation. The gases produced are mostly hydrogen (mono and diatomic, more than 90% of gases released) and, to a lesser degree, methane and carbon monoxide and dioxide.

The potential consequence of this release of hydrogen is the formation of explosive atmospheres in the rooms or equipment where these waste packages are placed. An explosion may occur, in the presence of a source of ignition, if the concentration of gas exceeds the lower explosive limit (LEL)[56].

Each zone/room in which the ILW-LL packages may transit, regardless of their container, can be the site of release of radiolysis gas and of formation of a potentially hazardous atmosphere. The rooms at risk are those in which the waste packages are grouped together in high quantities with accumulated degassing and those in which the waste packages are contained with the possibility of accumulation of hydrogen in a leaktight closed cavity.

In the majority of the rooms of the surface facility, the waste packages are handled one at a time. The zones in which waste packages are more numerous are the transport container unloading cells and the buffer zones.

[56] The LEL is 4% for hydrogen in air

During transfer between the surface facility up to the disposal cells, the number of disposal packages transferred is unitary. The quantity of radiolysis gases present in the ramp and the drifts is therefore very limited. However, the waste package is transferred into these zones in a restricted volume, assumed to be leaktight, that is the transfer cask. The risk of formation of an explosive atmosphere due to accumulation of hydrogen in the transfer cask is therefore analysed.

As the cell is filled, the number of disposal packages and therefore the quantity of radiolysis gas released within the cell increase as a consequence. The risk of an explosive atmosphere forming due to the accumulation of hydrogen in ILW-LL disposal cells is therefore analysed.

The zones that present a potential risk of an explosive atmosphere forming are:

- transport container unloading cells;
- unprepared disposal package buffer zone;
- complete disposal package buffer zones;
- ILW-LL package transfer casks;
- ILW-LL disposal cells.

The degassing rates for ILW-LL packages taken into account in studies are shown in Chapter 1 of Volume II of this document. The value applied is 40 L/year per disposal package with a sensitivity evaluation at 100 L/year per disposal package.

2.1.5.2 Analysis method

The risk of radiolysis is analysed by assessing the provisions to be made to control the risk of an explosive atmosphere forming in rooms or zones containing primary packages or disposal packages and to eliminate any risk of explosion in the Cigeo facilities, by applying sufficient margins, for all operating situations.

Initiating events of internal and external origin may lead to damage or unavailability of active or passive systems used to manage the risk of explosive atmospheres forming under normal operating conditions. The incident and accident operating conditions depend on the zone considered and are largely based on such variables as the presence of ventilation providing removal and dilution of the radiolysis gases produced, and the period for which an accumulation of radiolysis gases is acceptable within a given zone.

The safety options considered to control the risk of an explosive atmosphere being formed in the rooms or zones at risk are indicated below and are broken down by room/zone:

- limiting the quantity of hydrogen produced. The prevention of appearance of an accumulation of hydrogen involves the limitation of the quantity of hydrogen at the source i.e. from the primary packages. This maximum quantity is covered by a requirement specified in the Cigeo waste package acceptance specifications.
  The primary packages and disposal packages received at Cigeo, and disposal packages produced by Andra using the primary packages received, will need to comply with the requirements taken into account for defining the design scenarios considered in terms of the risk associated with radiolysis gases in the surface, transfer and underground facilities.
  At this stage provisions are under consideration to accept a limited number of disposal packages, whose hydrogen production is higher than the value specified generically. These waste packages will be subject to case-by-case management with setting up of derogations;
- evacuating the hydrogen produced. Installing a ventilation system promotes the mixing, dilution and removal of radiolysis gases;
- and prevents hydrogen accumulation zones. In the ILW-LL disposal cells, in normal operation, maintaining a ventilation operating mode with turbulent air flow helps to prevent creation of dead zones (potential hydrogen accumulation zones).

In order to obtain sufficient margins in relation to the time taken to reach LEL in the rooms identified as at risk for all operating conditions of the facility with the aim of eliminating any risk of formation of an explosive atmosphere within these rooms, the following requirements must be met:

- apply a margin in relation to the LEL (Lower Explosive Limit) for the design of provisions required to control the risk of formation of an explosive atmosphere. The following design objectives have been defined: Always remain below:
  - ✓ 25% of LEL in all facilities (i.e. 1% hydrogen) in normal and degraded operation;
  - ✓ 75% of LEL (i.e. 3% of hydrogen) in incident and accident operating conditions (taking account of the possibility of reaching 25% of LEL in normal operation);
- apply a bounding degassing rate per disposal package regardless of the zone studied.

2.1.5.3 Rooms in the surface facilities of the ramp zone

The rooms in the surface facilities of the ramp zone that are potentially concerned by the risk of radiolysis are:

- the transport containers unloading cells (ET-H and ET-V);
- unprepared disposal package buffer zone;
- West side prepared disposal package buffer zone;
- East side prepared disposal package buffer zone;

<u>In normal operation</u>, the rooms are ventilated to encourage mixing and dilution of the radiolysis gases in order to prevent the creation of dead zones and to remove the radiolysis gases. This assumption acts as the basis for defining minimum ventilation conditions for the cells.

The initial assessments show that the ventilation flow rates specified for the design in the rooms at risk are clearly higher than the minimum flow rates allowing for guarantee of an H_2 concentration by volume in the air lower than 1% (factor of about 106). At this stage, the air flow in the rooms has not been studied in detail. However, the margin in relation to the specified flow rate is sufficiently large that taking account of air flow does not compromise the current ventilation design.

<u>In the event of stopping operation of the ventilation systems</u>, the radiolysis gases may accumulate in the rooms identified as being at risk. It is therefore necessary to assess the time taken for an explosive atmosphere to form; the criterion considered entails reaching a fixed H_2 concentration of 3%, with a conservative assumption that, in normal operation, the acceptable limit of 1% H_2 is reached.

For the assessments, a rate of 40 L/CS/year is considered, whatever the disposal package. The rooms are assumed to hold the maximum number of waste packages. The rooms are assumed to be sealed. The accumulation of all gases produced within the capacity of the rooms is taken into consideration. In the absence of ventilation of these rooms, it is considered, as a conservative assumption, that the gases accumulate at the interface with the zone containing the sources of emissions with a height of 10 cm over the whole of the surface concerned.

On the basis of these assumptions, the times taken to reach an H_2 concentration of 3% in the rooms considered in the event of loss of ventilation are shown in Table 2.1-.

Table 2.1-10 Time taken to reach an H_2 concentration of 3% for rooms in surface facilities

Room	**Time taken to reach an H_2 concentration of 3% for 40 L/CS/year** *(weeks)*
ET-H unloading cell	90
ET-V unloading cell	23
Unprepared disposal package buffer zone	46
West side prepared disposal package buffer zone	65
East side prepared disposal package buffer zone	51

In the most pessimistic case (ET-V package unloading cell), an H_2 concentration of 3% is reached after about 23 weeks of ventilation loss.

At a rate of 100 L/disposal package/year, an H_2 concentration of 3% is reached after about nine weeks of ventilation loss.

Provisions

Ventilation design provisions (positioning of air supply and extraction outlets in the rooms) must be made to prevent hydrogen accumulation in certain areas within rooms.

Provision is made for monitoring to check ventilation performance (ventilation flow rate).

Given the times taken to reach an H_2 concentration of 3%, there is no risk of an explosive atmosphere forming in the event of a ventilation failure in rooms identified as being at risk in the ramp zone surface facilities.

2.1.5.4 ILW-LL casks

In normal operation, the cask is used to transfer an ILW-LL disposal package from the surface to the disposal cells. Given the speeds of the transfer vehicles and equipment and the times allocated to the various handling operations, the cycle time between loading a waste package in the cask at the surface and unloading the cask in a disposal cell is estimated at about three hours. A period of 48 hours is allowed to take any operating constraints into account.

The H_2 concentration inside the cask (cask considered gastight) is estimated at about 0.18% after 48 hours, allowing for an accumulation in the upper part of the cask. This value is below the limits defined in Section 2.1.5.2.

For a situation in which the package handling system stops, leading to the immobilisation of the transfer cask, the disposal package is considered to be in the cask. Hydrogen accumulates inside the cask.

For assessment purposes, a rate of 40 L/disposal package/year is considered, whatever the disposal package. It is considered that the cask is leaktight and that gases accumulate according to two distribution patterns: (i) a homogenous dilution of the gas in the cavity or (ii) a stratification in the upper part of the container.

Based on these assumptions, Table 2.1- shows the times before an H_2 concentration of 3% is reached in a cask considered leaktight and containing a disposal package, with the pessimistic assumption that the acceptable limit of 1% H_2 has been reached under normal operating conditions.

Table 2.1-11 Times taken to reach an H_2 concentration of 3% in a cask

	Distribution assumptions	Time taken to reach an H_2 concentration of 3% for 40 L/disposal package/year (weeks)
Cask	Homogenous accumulation	32
	Accumulation in upper section	3

For a rate of 100 L/disposal package/year, an H_2 concentration of 3% is reached some nine days after the immobilisation of the cask, assuming that hydrogen accumulates in the upper part of the cask. The time increases to 13 weeks based on the assumption of homogenous hydrogen accumulation.

Provisions

Provisions made regarding the risk of hydrogen accumulation in the cask are based on:

- provisions concerning handling equipment in order to:
  - ✓ limit the occurrence of equipment failure;
  - ✓ restart the defective equipment;
  - ✓ lower the cask;
  - ✓ release the blocked equipment, and use other equipment to pick up the cask;
- material provisions: the cask has two equipped openings for sweeping the air inside it.

Given the length of time before hydrogen concentration criteria are reached, the provisions made, such as repairing handling equipment in the event of failure, removing the cask or sweeping the air inside the cask, there is no risk of an explosive atmosphere forming in the cask in normal operation, or in the event of incidents of internal or external origin leading to the immobilisation of the cask.

2.1.5.5 ILW-LL disposal cells

In normal operation, the ILW-LL disposal cells are ventilated to promote mixing and dilution of radiolysis gases in order to prevent the creation of dead zones and evacuate radiolysis gases. This assumption provides the basis for defining minimum ventilation conditions for disposal cells and leads to the following provisions:

- use of a turbulent ventilation operating mode in ILW-LL disposal cells to prevent the formation of pockets of gas in dead zones;
- ventilation flow rates in ILW-LL disposal cells, currently evaluated between 1,620 m^3/h and 4,500 m^3/h, depending on the type of tunnel, to ensure the removal of radiolysis gases produced by disposal packages and guarantee that the hydrogen concentration remains below 1%.

In normal operation, ventilation design for ILW-LL disposal cells ensures effective dilution and removal of radiolysis gases.

If the ventilation shuts down in an ILW-LL disposal cell, radiolysis gases may accumulate in the tunnel. The time taken for an explosive atmosphere to form in this zone is therefore assessed, applying an H_2 concentration criterion of 3%, and pessimistically assuming that the acceptable limit of 1% H_2 was reached under normal operating conditions.

For assessment purposes, a rate of 40 L/disposal package/year is considered, whatever the disposal package. The disposal cells are assumed to contain the maximum number of waste packages. The accumulation of all gases produced within the volume is taken into consideration (sealed disposal cells). In the absence of ventilation in the disposal cells, it is considered that gases accumulate around the zone containing the emission sources over a height of 17 cm covering the entire surface concerned.

Based on these assumptions, the H_2 concentration of 3% is reached after about five weeks in the event of loss of ventilation.

At a rate of 100 L/disposal package /year, an H_2 concentration of 3% is reached after about two weeks in the event of loss of ventilation.

<u>Provisions</u>

Provisions made regarding the risk of an explosive atmosphere forming in an ILW-LL disposal cell are based on:

- a system to manage loss of ventilation in ILW-LL disposal cells:
  - ✓ design of "passing" ILW-LL disposal cells:
    - elimination of the common mode of simultaneous loss of ventilation air intake and exhaust, for example following a ground collapse or a loss of electrical power supply;
    - easy access for maintenance of ventilation system ducts and components;
  - ✓ design of ventilation system and monitoring equipment:
    - guarantee of a certain level of extraction in the event of internal and external hazards;
    - restoral of post-hazard ventilation within a time compatible with the time before an explosive atmosphere is formed;
    - redundant power supply and instrumentation and control for the ventilation system;
  - ✓ additional fans stored at the surface;
- hydrogen concentration monitoring at the HEPA filters in disposal cells.

Given the length of time before hydrogen concentration criteria are reached and the provisions made to ensure the reliability of tunnel ventilation, there is no risk of an explosive atmosphere forming in the ILW-LL disposal cells, in normal operation and under conditions of loss of ventilation.

2.2 Internal Hazards

2.2.1 Handling risks

2.2.1.1 Source of risk

<u>Description of handling equipment</u>

The handling risk concerns all loads handled, but for the purpose of this study, the analysis focuses on loads containing radioactive materials.

The entire Cigeo nuclear process centres on the ramp zone surface facility, the waste package transfer ramp and the underground facility.

During the process, from the arrival of the transport containers up to the emplacement of the disposal packages in the disposal cells, the radioactive loads handled are in the following forms:

- transport containers (ET) containing the primary packages (CP) and/or, where applicable, disposal packages prepared at the producers' sites (CS-P);
- primary waste packages;
- unprepared disposal packages, i.e. disposal packages for which the disposal container lid is in place but not screwed down;
- disposal packages;
- transfer casks containing disposal packages (CS).

These loads are handled using various types of equipment, which are mainly used in lifting and transfer operations. This equipment includes:

- lifting equipment, comprising:
  - ✓ bridge cranes (including gantries);
  - ✓ lift tables and lifts;
- rail-guided transfer vehicles and equipment including:
  - ✓ vehicles used for long-distance transfers such as carts and shuttles running in the underground facility;
  - ✓ vehicles used for short-distance transfers such as carts and transfer tables and carriages at the surface, transfer carriages, etc.;
  - ✓ equipment used for transfers requiring precise positioning such as the docking table;
- the ramp transfer system;
- other special equipment such as turntables, the pusher robot for HLW disposal cells, stacking cart and stacking crane for ILW-LL disposal cells;
- accessories (support frame, tipping device, docking facade, etc.).

The following tables show the equipment used to handle radioactive loads used during the process from the surface facility to the disposal cells. Their purpose is to help identify the risks, giving details such as the objects handled and the order of magnitude of maximum transfer speeds (Vm) and handling heights (Hm) considered at this stage.

Table 2.2-1 List of handling equipment used for receiving transport containers (ET)

Room	Handling equipment	Equipment function	Object	V_{max} *(m/min)*	H_{max} *(m)*
Train (un)loading bay	Gantry crane	Unloading ETs from trains or trucks and placing them on a rail lorry	ET-V, ET-H	TBD	2
Train loading/unloading bay ET-V reception area 1 ET-H reception area 2 ET-NC processing room	Rail lorry	Routing ETs to the various bays and areas	ET-V, ET-H, ET-NC	15	NA
	Turntables	Turning the rail lorry	ET-V	NA	NA
	ET support frame	Interface between rail lorry and ETs	ET-V, ET-H	NA	NA
ET-V receiving area 2	Bridge crane	Upending (ET H/V), lifting and transferring ET-Vs to the transfer cart in a vertical position	ET-V	TBD	< 6
ET-H receiving area 3	Bridge crane	Transferring ET-Hs to the C3 inspection station and preparation airlock cart	ET-H	TBD	< 2
Cart access corridor Transfer carriage movement ET-V preparation and docking rooms Preparation and C4 inspection room	ET-V transfer carriage	Transferring ET-Vs to various rooms	ET-V	5	NA
	ET-V cart	Transferring ET-Vs between the preparation stations and lifting for unloading	ET-V	10	<3.5
	ET-V docking frame	Adapter for unloading all types of ET-V	ET-V	NA	NA
Interface of ET-H receiving area 3 and ET-H preparation airlock	ET-H transfer cart	Transferring an ET-H from the unloading bay to the preparation airlock	ET-H	10	NA

Table 2.2-2 List of handling equipment used for unloading primary packages (CP) and placing them in the disposal container (Cts)

Room	Handling equipment	Equipment function	Object	V_{max} *(m/min)*	H_{max} *(m)*
ET-V unloading cell	Bridge crane	Loading/unloading CPs on/from ET-Vs	CP CS-P	NA	< 6
ET-V unloading cell C5 inspection cell	Transfer cart	Transferring CPs from the unloading cell to the C5 inspection cell	CP CS-P	1	NA
C5 inspection cell	Bridge crane	Transferring CPs from cart platforms to C5 inspection stations	CP CS-P	TBD	< 1.5
Cell for placing CPs in CSs	Bridge crane	Loading CPs into CtS	CP CS-P	TBD	< 1.5
ET-H unloading cell C5 inspection cell	Rail-mounted fork-lift truck	Loading/unloading CPs on/from ET-Hs	CP CS-P	TBD	TBD
	Bridge crane	Loading CPs into CtS	CP CS-P	TBD	< 1.5
	Turntables	Changing direction of carts	NA	NA	NA

Table 2.2-3 List of handling equipment used for conditioning disposal packages (CS)

Room	**Handling equipment**	**Equipment function**	**Object**	**V_m** *(m/min)*	**H_m** *(m)*
Process circulation corridors Cell for placing CPs in CSs Unprepared CS buffer zone Prepared CS buffer zone ILW-LL CS conditioning cell- C7 inspection and cask loading cells (ILW-LL and HLW)	CS transfer carriage and transfer cart	Transferring prepared or unprepared CSs into various rooms during conditioning	CS	10	< 0.5
Cell for placing CPs in CSs	Lift tables for transferring unprepared disposal packages	Lifting an empty CtS vertically from elevation 0 to 6 m then, when full, lowering it from 6 m to elevation 0	CS	TBD	< 6
ILW-LL CS conditioning cell	Bridge crane	Handling ILW-LL CS lids and equipment used for ILW-LL CS conditioning	CS	TBD	< 0.3
HLW CS conditioning cell	Bridge crane	Handling unprepared HLW CSs (without lids) in cradle/basket to various stations for HLW CS conditioning	CS	TBD	< 0.3

Table 2.2-4 Table of handling equipment used for the disposal package (CS) buffer zone and loading disposal packages in the cask

Room	Handling equipment	Equipment function	Object	V_m (m/min)	H_m (m)
C7 inspection and ILW-LL cask loading	Lift	Placing CSs on the ILW-LL loading table	ILW-LL CS	2	< 1.2
	ILW-LL CS loading table	Inserting CSs into the ILW-LL cask	ILW-LL CSs	5	< 0.3
C7 inspection and HLW cask loading cell	Bridge crane	Placing CSs on HLW tipping device	HLW CS	TBD	< 0.3
	HLW tipping device	Tipping HLW CSs	HLW CS	NA	TBD
Cask storage area	Limited lifting machine (MLL)	Handling ILW-LL and HLW casks in the cask storage area	HLW casks ILW-LL casks	20	< 0.3
Cask storage area Connecting drift to ramp head	Surface shuttles	Transferring ILW-LL and HLW casks between the top ramp station and the cask storage area	HLW casks ILW-LL casks	30	< 0.3
Cask storage area Connecting drift to ramp head	Turntables for surface shuttles and MLL	Changing direction of casks and shuttle	NA	NA	NA
	CS transfer cart	Inserting ILW-LL CSs and HLW CSs into C7 inspection cells	ILW-LL CS HLW CS	10	< 0.3
	ILW-LL/HLW docking facade	Transferring CSs from the cask loading cell to the cask docked on the cask storage area side	NA	NA	NA

Table 2.2-5 List of handling equipment used for transferring casks from the surface to the access drifts

Room	Handling equipment	Equipment function	Object	V_m (m/min)	H_m (m)
Head of waste package transfer ramp	Ramp transfer system (cable railway)	Transferring casks from the surface facility to the underground facility	HLW casks ILW-LL casks	150	NA
Bottom station Connecting drifts Connecting drift/access drift intersections	Bottom transfer cart	Transferring ILW-LL and HLW casks in the connecting drifts from the bottom station to intersections with ILW-LL and HLW access drifts	HLW casks ILW-LL casks	170	< 0.3
Connecting drifts	Bottom transfer cart turntables	Turning carts	NA	NA	NA

Table 2.2-6 List of handling equipment used for placing ILW-LL and HLW disposal packages in disposal cells

Room	Handling equipment	Equipment function	Object	V_m (m/min)	H_m (m)
Connecting drift-access drift intersection	Track turntables	Rail track orientation	NA	NA	NA
ILW-LL access drifts	ILW-LL shuttle at bottom	Picking up and transferring the ILW-LL cask to the docking table	ILW-LL casks	30	< 0.3
HLW access drift	HLW shuttle at bottom	Picking up and transferring the HLW cask to the HLW disposal cell.	HLW cask	170	< 0.3
ILW-LL access drift-ILW-LL handling cell interface	Docking table	Secured approach and precise coupling of cask with handling cell door	ILW-LL casks	5	NA
ILW-LL access drift-ILW-LL handling cell interface	Docking facade	Transferring the ILW-LL disposal package from the ILW-LL access drift to the ILW-LL handling cell	NA	NA	NA
ILW-LL handling cell	Receiving table	Transferring disposal packages from the cask to the lift	ILW-LL CSs	5	< 0.3
	Lift	Picking up the ILW-LL disposal package placed on the receiving table and lifting it to the appropriate height for it to be picked up by the stacking crane or the stacking cart	ILW-LL CSs	5 for CS6 and 7 2 for CS1 to CS5	< 4
Handling cell and ILW-LL disposal cell	Stacking crane (CS1 to 5)	Using fork-lifts to place an ILW-LL disposal package on the lift and routing it to its position in the disposal cell	ILW-LL CSs	20	< 0.3
	Stacking cart (CS6 and CS7)	Using fork-lifts to place an ILW-LL disposal package on the lift and routing it to its position in the disposal cell	ILW-LL CSs	20	< 0.5
HLW disposal cell	Pusher robot	Positioning the HLW disposal package previously placed at the cell head by the HLW cask and refitting the disposal cell plug	HLW CS	20	NA

Note: Waste package handling operations can be performed in reverse, except for removing HLW packages from a disposal cell, which requires the use of a puller robot.

Risk identification

Whether or not radioactive materials are involved, load handling using the various types of handling equipment found at the Cigeo facility (bridge cranes, cart, transfer carriage, etc.) can generate risks relating to:

- the handling equipment used;
- interfaces between the different types of handling equipment: for example when a package handled by one piece of equipment must be picked up by another.

Whether they contain radioactive materials or not, load handling using the various types of handling equipment found at the Cigeo facility (bridge cranes, cart, transfer carriages, etc.) may entail the risk of the load being dropped during handling. The falling load could then hit a “safety target” or become a “safety target” itself.

Transferring loads can also entail risks of collision between two handled loads or between a handled load and a stationary piece of equipment or a wall.

Although the handling risk concerns all handled loads, the analysis in this study focuses on loads containing radioactive materials.

A falling load or collision between several objects may cause:

- dispersion of radioactive substances in the event of containment failure (the load itself or a containment equipment struck by a falling load), with a potential environmental impact;
- external exposure of personnel in the event of damage to radiation shielding;
- loss of equipment performing a facility safety function.

The analysis also considers the risk of the process being interrupted or the drive train being stopped to ensure that the above situations do not generate additional risks for facilities.

- ***Risks associated with lifting equipment***

The main risk associated with bridge crane type equipment concerns a load being dropped during handling since this may damage the load or cause damage to equipment important for protection. A falling load can have several causes, including:

- the use of handling equipment that is not suited to the load, including when handling is performed by an operator;
- a broken handling drive train component.

A failure when using bridge cranes can also lead to a collision and therefore damage the handled load or the equipment involved in the collision. The collision may have several causes, including:

- human error leading to the handled load deviating from its transfer path, when handling is performed by an operator;
- an obstacle on the bridge crane track;
- sensor failure (limit switches, mapping error, etc.).

As lift tables are designed to preclude the risk of falling loads during handling, the main risks considered are:

- the slow collapse of a lift table;
- damage to equipment or the floor due to incorrect positioning of the lift table or to excessive travel.

- ***Risks associated with rail-guided transfer equipment***

Rail-guided transfer equipment (carts, shuttles, transfer tables) is used throughout the process to allow transfers at low heights. Transfer speeds may reach 20 m/min for surface facility equipment and 170 m/min for underground facility equipment.

The use of rail-guided systems limit the risks of collision (especially for changes in direction). The following risks are nevertheless considered:

- collision of transfer equipment with an object located on its path;
- collision of transfer equipment with other equipment located on its running track;
- equipment derailment;
- load tipping over due to excessive speed, untimely braking or an impact.

- ***Risks associated with the ramp transfer system (cable-traction rail-guided transfer system)***

The ramp transfer system cart is used to transfer casks containing a disposal package to the underground structures and to lift empty casks during operations and, if necessary, during removal operations. It runs in a straight line on rails, with a cable for towing the equipment. It travels at about 150 m/min.

The main risks associated with the ramp transfer system are:

- excess speed during transfer to the bottom;
- collision with an object located in its path;
- the ramp transfer systems comes to a sudden halt causing the cask to come loose.

- ***Risks associated with special equipment***

Turntables are used to change the direction of a transfer vehicle or turn the rails to allow another transfer vehicle to approach and pick up the load. The main risk associated with a turntable is incorrect positioning during the approach of a shuttle or cart. A failure in the interface between the turntable and the transfer vehicle could lead to the risk of derailment.

The stacking crane and stacking cart used during the emplacement process (disposal in layers and in a single layer) are designed to limit the risks of falling loads and to mitigate their impact. A risk of collision is also considered.

The pusher robot is mainly concerned with collision risks (between waste packages).

- ***Risks associated with accessories***

The main risks associated with this equipment are:

- risks at the interfaces, in particular for support frames and docking facades;
- falling load due to a failure on the HLW tipping device during the insertion of an HLW disposal package into the cask.

- ***Risk of the package handling drive train jamming***

Handling drive train jamming may be caused by equipment or operating failure, or the loss of electrical power supply. The main consequences are an impact on the operation and availability of the facility.

Drive train jamming may lead to various situations, including:

- equipment jammed in a transitory position with the risk of a load being dropped or tipped over: this situation concerns equipment such as bridge cranes (including the stacking crane), lift tables and the ramp transfer system. For rail-guide transfer vehicles, there is no loss of stability in the event of jamming. Transitory situations are therefore safe and risk-free. The main examples to illustrate these situations are as follows:
  - ✓ when primary packages are being unloaded in a package unloading cell, a drive train failure during crane handling could lead to an additional risk of falling loads;
  - ✓ at interfaces between the various equipment, in particular for transfer cask (un)loading phases, an interruption in the sequence of operations could lead to a package being jammed in a transitory position;
- process jamming while the pusher robot is placing HLW disposal packages in the disposal cell. This situation presents no risk for facility safety;
- prolonged drive train jamming likely to lead to risks associated with heat or radiolysis. Prolonged jamming of a waste package in the cask could, in view of the limited volume of the cask, lead to:
  - ✓ hydrogen accumulation;
  - ✓ a rise in temperature likely to damage cask components (neutron shielding).

These risks are covered in Sections 2.1.1, 2.1.4 and 2.1.5, respectively, for "process" rooms or disposal facilities.

2.2.1.2 Preventive measures

<u>General provisions applicable to all equipment</u>

In order to guard against handling risks, the design and dimensions of the facilities and equipment take into account the following rules:

- compliance with regulations in force;
- use of design codes incorporating margins;
- selection of materials and equipment designed to withstand a radioactive environment;
- application of the single failure criterion, in particular for braking systems and the lifting chains on lifting equipment;
- consideration of conditions outside normal operation (loss of utilities, earthquakes, etc.);
- incorporation of nuclear industry operating experience feedback.

In normal operating mode, handling is adapted to the types of handling equipment used. Given the radioactive nature of many waste packages, preference is given to automatic or remote-controlled handling and operations. Instrumentation and control design provisions are included to prevent handling risks. Operations requiring human intervention will be performed by suitably trained and qualified operating personnel.

<u>General provisions for lifting equipment</u>

General provisions are listed below. The provisions made must be adapted to the equipment and the associated risks:

- lifting systems are redundant and equipped with fail-safe braking;

- the equipment used to secure the load is designed to mechanically lock the load to prevent it from falling:
  - ✓ on lifting beams, mechanical systems are used to lock handled loads (fail-safe device on limited lifting machine (MLL));
  - ✓ lifting beam opening/closing systems can only be operated when the waste package has been put down. Untimely opening is therefore impossible when the waste package is held by a beam during the handling phases;
  - ✓ when the package is attached to the bridge crane, a coding system ensures that the beam is suited to the package;
  - ✓ lifting chain tensioning ensures that the load is properly secured for crane handling operations;
- equipment travel is restricted to clearly defined zones (limit switches, stops) and at reduced speeds in zones at risk;
- the control logic only authorises a single movement at a time;
- zones used for transferring and placing waste packages in disposal cells are identified to prevent the risks of contact between a handled package and an obstacle;
- on detection of anomalies (excess speed, obstacle, etc.), the movement is stopped;
- lifting, translation or upending speeds are low;
- bridge cranes are equipped with lift prevention systems and derailment prevention systems, if necessary;
- wherever possible, lifting heights are limited to the qualification heights of the handled loads. At this stage of design, the option considered is to limit the lifting height of primary packages and disposal packages to 1.2 m, wherever possible. The tables below show the lifting heights of the various handled loads;
- overhead loads must not pass over equipment important for protection or other disposal packages.

<u>Provisions for the stacking crane</u>

The stacking crane is designed to limit the risk of a falling disposal package. The provisions made regarding collision risks are the same as for crane:

- lifting systems are redundant and equipped with fail-safe braking;
- equipment movements are restricted to clearly defined zones (limit switches, stops) and at reduced speeds in zones at risk;
- the control logic only authorises a single movement at a time;
- zones used for transferring and placing waste packages in disposal cells are identified to prevent the risks of contact between a handled package and an obstacle;
- on detection of anomalies (excess speed, obstacle, etc.), the movement is stopped;
- lifting, translation or upending speeds are low;
- lifting heights are limited to about 30 cm.

<u>General provisions for rail-guided transfer equipment</u>

Concerning the transfer equipment, the risks of dropping, overturning and collision are controlled by the following provisions:

- the use of rail-guided systems to guard against the risk of collision following a change in trajectory;
- low transfer speeds depending on loads handled;
- the use of guided transfer equipment with a lift prevention and derailment prevention system, if necessary (hold-down brackets);
- transfer equipment is equipped with fail-safe brakes - service brake, emergency brake - for safety purposes;
- handled loads are secured to transfer equipment by a locking system;

- the braking systems are redundant and used by the automatic stopping devices on detection of an anomaly (excess speed, obstacle, etc.);
- the braking systems are designed so that the stopping distance is compatible with detection and induces maximum deceleration that is compatible with the design of the locking systems for the handled loads;
- in the underground structures, the electrical power supply for the tracks is designed to prevent the simultaneous presence of two carts or two shuttles within the same sector;
- on passing through the doors, an interlock between the transfer equipment and the door prevents the risk of collision;
- waste package transfer, placement and storage zones are identified to prevent the risks of collision. Particular attention is paid to clearance of handling tracks;
- additional provisions for the ramp transfer system:
  - ✓ the cable drive system of the vehicle on the ramp is backed up by two motor pulleys in a pulley block loop (operation possible with a single motor pulley);
  - ✓ motor pulley machinery braking is ensured by service brakes and fail-safe emergency brakes;
  - ✓ In the event of a machinery braking malfunction, of even a cable break, vehicle braking is ensured by two types of fail-safe brake that are independent of the machinery braking and with no common modes: the emergency stop brake (FAU: shoe brakes) and the emergency brake (AUS: track friction brake).

<u>Equipment interface provisions</u>

Prevention of risks in interfaces is mainly based on the control of instrumentation and control of various position sensors incorporated in the equipment for checking correct positioning:

- all turntables are equipped with an adjusting and interlocking system between the turntable and the associated transfer equipment to prevent the risk of incorrect positioning on a table during the approach of a transfer vehicle;
- the support frames are designed to eliminate the risk of a transport container being placed on the wrong frame. These provisions particularly concern the management of human and organisational factors;
- the electrical power supply includes a blocking system to prevent the bottom cart or the surface shuttle from moving when the ramp transfer system is not positioned correctly at the top or bottom station;
- during the insertion and removal of disposal packages into and out of the casks through the docking facades, guides are used to eliminate any risk of an incorrect interface between the various items of equipment, as well as holding the objects being handled;
- when the stacker crane retrieves the disposal package on the lift, lateral anti-tilt guides are used to keep the disposal package within the lift cage;
- the lift tables have position sensors and reduced travel to ensure correct positioning between the equipment involved and to limit the risk of crushing in the event of incorrect positioning.

<u>Provisions concerning the risk of jamming</u>

Preventive maintenance programmes are prepared for equipment.

In the event of loss of electrical power supplies, equipment presenting a risk of jamming has an independent electrical power supply. This is described in Chapter 2.2.4.

A test programme before commissioning and in degraded mode will be carried out to check facility equipment performance, particularly for interfaces.

2.2.1.3 Monitoring systems

Monitoring devices are installed on the handling equipment to ensure that they operate under normal conditions and to monitor the occurrence of faults leading to degraded conditions in the facility:

- speed sensors;
- anti-collision sensors;
- limit switches;
- specific characteristics of the ramp transfer system:
  - ✓ the ramp transfer system has a panel of sensors used to check that operations are performed under normal operating conditions. In particular, speeds are measured using two independent systems, without common modes: one electrical system and one mechanical system. Furthermore, sensors on the force measuring pins of the ramp transfer system synchronisation pulleys measure any cable slackening or even possible breakage;
  - ✓ the condition of the cable is verified by magnetic particle examination (facilitated by the pulley block loop).

Production monitoring provisions are included to locate waste packages.

Handling operations are supervised from the control room. This ensures correct performance of operations and identification of any process failures (incorrect positioning, load fastening error, etc.) before they lead to deviation from normal operation. For hands-on operations performed by operators, a preliminary check is systematically performed to ensure that loads are properly secured before lifting to reduce the risk of errors.

Handling equipment is subject to a maintenance and monitoring programme.

Use of standard industrial equipment, particularly for bridge cranes at the surface ensures the availability of operational feedback, which can be used for monitoring curative maintenance to anticipate any failures that may occur on similar equipment.

2.2.1.4 Mitigation measures

<u>General provisions</u>

In terms of mechanical strength, transport containers and primary packages are specially designed to withstand falls. Transfer casks and disposal containers are designed and dimensioned for the risk of falls, impacts or collisions identified in the Cigeo facilities. In addition, the casks are equipped with feet and can therefore be set down at any time with complete stability.

Most primary packages withstand falls from a height of at least 1.2 m and guarantee containment of radioactive materials in this event (see Volume II, Section 1.6). Transfer casks are designed to withstand falls when they land on their feet. Disposal containers are designed to retain mechanical integrity falls from a height of 2.3 m and guarantee containment radioactive materials in this event (see Volume II, Section 1.4.3).

Load lifting heights are limited as far as possible to below their fall qualification height (see previous tables). If this is not possible, shock absorber mats are installed to prevent the consequences of a fall (for example, for handling a transport container without its protective covers and handling a disposal package using the lift in the handling cell).

Filling ILW-LL disposal cells in layers using the stacking crane thus limits the lifting height of disposal packages to less than 15 cm.

The HLW tipping device is equipped with a holding basket that can be adapted to all disposal packages and prevents any risk of falling loads.

Regarding risks of collision, for all of the handling equipment (including bridge cranes and guided transfer equipment), load travel speeds are limited and the deceleration ramps are configured on equipment instrumentation and control when approaching the various stopping zones. For example, the transfer equipment has translation speeds limited to about:

- 15 m/min maximum for equipment carrying transport containers;
- 10 m/min for equipment transporting primary packages or unprepared disposal packages;
- 150 m/min (9 km/h) for the ramp transfer system.
- 170 m/min for shuttles transporting casks in the underground structures;

For the equipment with the highest nominal speeds:

- shock absorber cylinders between the ILW-LL or HLW casks and the bottom transfer carts mitigate the impact of collision with a rigid obstacle on the tracks;
- buffers at the end of the track on the ramp transfer system absorb any impact on its arrival at the station;

For the guided transfer equipment, the potential speeds of an impact with a rigid obstacle produce impacts with energies lower than a fall from a height of 1.2 m.

The casks are designed for a deceleration of 1g.

The transfer equipment and the provisions made to prevent the risk of overturning (securing integrity of rail assemblies; equipment; load) are designed to resist the forces due to a collision in order to mitigate the impact.

Wedging devices in the ILW-LL cask are used to secure the waste packages in a stable position in the event of collision or if the transfer equipment or vehicle comes to a sudden halt.

<u>Provisions regarding the risk of jamming</u>

In the event of jamming, all the equipment includes a function to lower the load in manual mode. This function is remote-controlled for equipment operating in cells where the dose rates do not allow human intervention. The procedure set up if a failure is detected is aimed at:

1. Completing transfer in degraded mode or lowering the load to make it safe.
   For the special case of the ramp transfer system, provisions are made in the event of failure to complete the transfer cycle, in terms of both electrical power supply and equipment failures;
2. Replacing the transfer equipment, particularly carts and shuttles of the underground facility to complete the operation in the event of a technical failure on the equipment;
3. Repairing transfer equipment if necessary, with casks designed to sufficiently attenuate the dose rate to a level compatible with human intervention;
4. Concerning a failure on equipment handling a cask, any degassing of the ILW-LL cask in the event of an extended failure (see Section 2.1.5).

Since design choices are based on using standard industrial equipment, operation will benefit from feedback on the main failures and, in the event of curative maintenance, will have access to the necessary spare parts.

In the event of jamming in a transitory position during handling, the provisions made for managing risks of loads being dropped or tipped constitute the mitigation measures.

2.2.1.5 Identification of operating situations

Based on the analysis of risks associated with handling operations and defence-in-depth provisions implemented, scenarios concerning various operating conditions are identified and shown in the tables below.

Scenarios are classified in accordance with the defence-in-depth provisions (or barriers) that must be cleared to trigger the unwanted event according to the methodology shown in Volume I.

Table 2.2-7 Incident situations associated with the handling risk

<table>
<tr><th rowspan="2"></th><th rowspan="2">Room/zone</th><th rowspan="2">Scenario</th><th colspan="2">Main defence-in-depth measures</th></tr>
<tr><th>Levels 1 & 2</th><th>Level 3</th></tr>
<tr><td rowspan="3">Surface</td><td>Train/truck unloading area</td><td>Transport container with primary packages dropped from a height of 2 m due to a human error when securing the load to the gantry crane</td><td rowspan="2">Training and qualification of operators for the operations to be performed</td><td rowspan="2">Drop-test qualification of B-type containers. Note: A-type containers are not all qualified for a drop from this height
Drop-test qualification of primary packages</td></tr>
<tr><td>Horizontal transport container receiving area</td><td>Transport container with primary packages dropped from a height of 1.2 m due to a human error when securing the load to the gantry crane</td></tr>
<tr><td>Cask storage area</td><td rowspan="2">Collision of an HLW or ILW-LL cask</td><td rowspan="2">Braking system on obstacle detection
Derailment prevention system</td><td rowspan="2">Low transfer speeds.
Casks designed to withstand collision and overturning</td></tr>
<tr><td>Bottom</td><td>Logistics support zone (ZSL)</td></tr>
</table>

Table 2.2-8 Accident situations associated with the handling risk

	Room/zone	Scenario	Main defence-in-depth provisions	
			Levels 1 & 2	Level 3
Surface	Vertical transport container receiving area	Drop < 6 m of B-type transport container without shock absorber covers following the failure of the bridge crane gripper system	design of bridge crane and gripping equipment: • Single failure criterion for bridge cranes • Fail-safe brakes • Mechanical interlocking of the load Training and qualification of operators for the operations to be performed + double inspection procedure and gradual tensioning during lifting	Shock absorber Robustness of B-type containers to withstand falls
	Vertical transport container unloading cell	HLW or ILW-LL primary package dropped from a height of 6 m onto another primary package due to a failure on the bridge crane gripper system when unloading a transport container.	Design of bridge crane and gripping equipment: Single failure criterion for bridge cranes Fail-safe brakes Mechanical interlocking of the load	Nuclear ventilation
	ILW-LL cask loading cell	ILW-LL disposal package dropped from a height of 1.2 m due to a failure on the bridge crane grip system	Mechanical interlocking of the load	Limited lifting heights Qualification of disposal packages for a drop Nuclear ventilation
	HLW cask loading cell	HLW disposal package dropped (from a height of about 3 m) or involved in a collision due to a failure on the bridge crane gripper system	Mechanical interlocking of the load	Drop test qualification of HLW packages Drop prevention device on tipping device (cage) Nuclear ventilation
	Ramp transfer system top station	Collision of an HLW or ILW-LL cask at the shuttle/ramp transfer system interface following incorrect alignment between the ramp transfer system and the shuttle	Shuttle design: obstacle detection, fail-safe brakes, lift prevention system, derailment prevention system Design of the ramp transfer system: sloping rails, redundant positioning sensors, interlocking between track power supply and shuttle or cart detection	Qualification of the cask for impact and of the cask/ramp transfer system interlock
	Ramp transfer system bottom station	Collision of ramp transfer system at bottom station at low speed	design of ramp transfer system: service and emergency brakes, obstacle detection, redundant instrumentation and control, automatic controller for machinery brake activation and traction shutdown	Shock absorber buffers Qualification of disposal packages and cask and interlocking of cask/ramp transfer system for impact

	Room/zone	Scenario	Main defence-in-depth provisions	
			Levels 1 & 2	**Level 3**
Bottom	ILW-LL disposal cell	Dropping a disposal package in the handling cell following the failure of the lift	Lift design: drop prevention guides, fail-safe system	Shock absorber Drop test qualification of disposal packages Nuclear ventilation
		Collision of a disposal package during disposal with another waste package in the cell		

Table 2.2-9 PUI design situations associated with the handling risk

	Room/zone	Scenario	Main defence-in-depth provisions
Surface	Vertical transport container receiving area	B-type transport container without shock absorber covers dropped from a height of 6m due to a failure on the bridge crane gripper system, combined with shock absorber failure	See corresponding accident scenario
	Ramp transfer system bottom station	Collision of ramp transfer system at bottom station at low speed combined with shock absorber buffer failure	See corresponding accident scenario
Bottom	ILW-LL disposal cell	Disposal package dropped in a handling cell due to a lift failure combined with shock absorber failure	See corresponding accident scenario

Table 2.2-10 Main excluded conditions associated with handling risk

	Room/zone	Scenario	Main provisions for prevention
Surface-bottom connection	Waste package ramp	Tilting of a cask transported on the ramp transfer system due to untimely activation of a braking system or a derailment	It is physically impossible for a cask to be tilted on the ramp (ramp gauge/cask gauge + ramp transfer system) Redundant cask locking on the ramp transfer system (4 feet)
	Top and bottom stations	Surface shuttle or bottom cart drops when the ramp transfer system is not present	Ramp transfer system design: interlocking between track power supply and shuttle or cart detection, preventing the shuttle from approaching in the absence of the ramp transfer system
	Bottom station	Loss of control of ramp transfer system following an equipment failure leading to a collision at high speed at the bottom station	Cable design (multi-strand) Ramp transfer system design: service and emergency brakes, Automatic controller for activating machinery brakes and shutting down of traction Redundancy of instrumentation and control

2.2.2 **Fire risk**

The occurrence of a fire requires the simultaneous presence of combustible materials, a source of ignition and fuel in sufficient quantity. A fire may, under certain conditions, lead to degradation or even loss of a safety function.

The control of the fire risk is based on implementation of a design approach including optimisation of the facilities. This design complies with the regulatory texts in force for basic nuclear installations. In particular, it concerns compliance with the Orders of 7 February 2012 (16) and 20 March 2014 (32) approving the decision on fire no. 2014-DC-0417. In view of the specific characteristics of Cigeo (surface-bottom connections and underground facility), namely a fire outbreak in a confined underground environment (depending on the ventilation conditions), and the specific characteristics of the conditions for emergency service operations, Andra has developed a fire baseline[57] for the design of Cigeo (31) which defines the fire safety objectives, the associated requirements and the analysis approach to be used.

2.2.2.1 Approach and methodology

The approach for achieving the objectives is based on the defence-in-depth principle to propose technical and organisational measures that are aimed at:

- preventing fire outbreaks;
- detecting and rapidly dealing with fire outbreaks to prevent them from spreading and developing into a major fire, and to restore normal operating conditions or, failing this, to reach and maintain safe conditions at the facility;
- limiting the development and spread of a fire that could not have been controlled, to minimise its impact on nuclear safety and to reach or maintain safe conditions at the facility;
- managing accident conditions resulting from a fire that could not be controlled to limit the impact on personnel and the environment.

The various successive levels of defence must be as independent as possible, with the robustness of the design based on the effectiveness and complementarity of these lines of defence.

The approach adopted for the analysis of fire-related risks consists in:

- identifying the sources of hazards and targets in relation to the target objectives,
- determining the preventive and protective measures appropriate to the issues,
- preparing scenarios that demonstrate that adequate provisions are made for fire protection (DPCI),
- taking into account the most unfavourable internal failure of an EIP called on by the incident or accident, whatever the initiating event considered.

This analysis is based, in particular, on the following approaches:

- a conventional fire approach providing the temperature in the compartment in relation to time. The ISO 834 conventional fire graph is used.
- a real fire approach (based on a list of combustible materials). Regardless of the shape of the fire load curve, in thermal terms it represents the source term that makes it possible to assess the real thermal risk for the room or for a target positioned to the side of the fire.

[57] This baseline was the subject of an assessment in 2014 by IRSN and a decision by ASN (see letter CODEP-DRC-2015-004834 of 7 April 2015)

2.2.2.2 Source of risk

Control of fire risk is based on identification of the main sources of fire hazard present in the facilities and the main targets to be protected from the effects of a fire. It requires identification of the main items of equipment necessary for operation (equipment associated with inspections of transport containers and waste packages, with preparation of disposal packages, with transfer and disposal) and a quantitative assessment of their fire load.

<u>Sources of fire hazard</u>

The sources of fire hazards present in the various rooms and zones of the facilities are listed below:

- Surface facilities in the ramp zone:
  - ✓ Rail terminal: the shunter used for moving rail trains;
  - ✓ train/truck loading and unloading hall: tractors and trailers, bridge crane, transport container transfer carts;
  - ✓ transport container receiving area: the transfer carts and the tractors and their trailers;
  - ✓ other rooms: the equipment and handling devices required for the nuclear process of inspecting transport containers, primary packages and disposal packages, disposal container loading, placing waste packages in casks and transferring waste packages;
  - ✓ electrical equipment rooms.
- Surface-bottom connections:
  - ✓ Waste package ramp transfer:
    - ramp transfer system vehicle;
    - the cables in the invert or in the effective protected routing section in and the electric boxes;
  - ✓ Service/emergency ramp:
    - emergency vehicles;
    - transfer equipment dedicated to the service ramp functions;
    - the cables in the invert or in the effective protected routing section in and the electric boxes;
  - ✓ Cross cuts between waste package ramp and service/emergency ramp: the equipment in the electrical technical rooms;
  - ✓ Fresh air shaft (VFE) between the surface and the operating ZSL: the combustible equipment of the lift cabins, and the miscellaneous combustible equipment for inspection of the shaft (lighting, for example). No electrical routing of power is specified in this shaft;
  - ✓ Exhaust air shaft (VVE) between the operating ZSL and the ventilation plant located at the surface in the shaft zone. No fire load will be continuously present. Only the shaft inspection and maintenance cradle will be present during the maintenance period.
- Underground facility:
  - ✓ Connecting drifts, access drifts and air return drifts:
    - the bottom carts, HLW casks undergoing transfer, the turntables,
    - the service and maintenance vehicles, emergency vehicles;
    - the cables in the invert or in the effective protected routing section in and the electric boxes;
    - the electrical equipment of the technical rooms located in the ILW-LL access drift;
    - the equipment in ILW-LL and HLW cask docking facades;
  - ✓ Cross cuts between drifts: the equipment of the electrical technical rooms and the power cables;
  - ✓ ILW-LL disposal cells:
    - the handling cell process equipment: lift table, bridge cranes, carts;
    - the stacking crane or stacking cart for disposal of ILW-LL packages;
  - ✓ ILW-LL disposal cell filtration room:
    - the HEPA filters and other filtration equipment;

  - electrical equipment and cables;
- ✓ Operating Logistics Support Zone:
  - the dedicated equipment for the functions of the rooms (electrical rooms, technical rooms, offices, waste storage, etc.);
  - the cables in the invert or in the effective protected routing section in and the electric boxes;
  - service vehicles - maintenance and emergency vehicles.

<u>Identification of targets</u>

The main targets to be protected in a fire situation are:

- primary packages;
- disposal containers;
- casks;
- disposal container in cell;
- HEPA filters, extraction fans and associated support systems;
- electrical power supply;
- Environment;
- personnel.

<u>Risk identification</u>

The approach adopted for identifying fire-related risks consists in postulating a plausible scenario for a fire outbreak in the vicinity of the fire hazard sources present in the various zones of the facility. The risk of this postulated fire outbreak developing and spreading is analysed to identify the risk control measures to be implemented to protect the targets identified in the facility.

A fire involving a waste package during its acceptance in a transport container (ET), its conditioning in a disposal package and its transfer into a disposal cell can entail a loss of safety function following a degradation of equipment, of civil works or of the waste package itself under direct attack by flames or by increase in temperature. These degradations are likely potentially to entail:

- a dispersion of radioactive materials in the event of failure of the primary containment system constituted by the waste packages or a provision impacted by fire (cask, room, etc.);
- external exposure of personnel in the event of damage to radiation protection;
- deformation of equipment or components for which criticality is inspected by geometry;
- loss of equipment providing a safety function.

The main risks identified are shown below.

- ***Risks associated with vehicles used to transfer and unload transport containers***

Transport containers arrive by train or truck. These vehicles can generate serious fires which may break out:

- on the road tractor due to the existence of the internal combustion engine, oil, tyres;
- in the locomotive engine.

These fires are likely to damage containers that are not fire-resistant and expose the waste packages to higher temperatures.

Once the containers have been unloaded onto the transfer cart for their contents to be unloaded in the unloading room, any fire starting in an electrical control box will be of lower intensity.

- ***Risks associated with waste package transfer vehicles in the facilities***

Waste packages are transferred by carts or shuttles on rails with a current collector shoe, which significantly mitigates the calorific potential. The residual potential fire corresponds to a fire breaking out in:

- an electrical cabinet;
- a hydraulic unit;
- the geared motors (presence of oil in a small quantity),

Likely effects:

- direct damage to the waste package when it is being unloaded from its transport container, during inspection or when it is placed in its disposal container, as well as in the underground facility when it is being placed in the disposal cell/tunnel,
- damage to the transfer cask, between the station where the waste package is loaded into it and its docking point at the head of the HLW and ILW-LL disposal cells.

- ***Risks associated with equipment required for disposal container and cask loading and for package unloading in the disposal cell***

The main risk associated with bridge cranes and lift tables is a fire breaking out on an electrical unit or motor. These fires, with limited intensity, may cause an equipment failure that could lead to the handled load being dropped or the lift table collapsing during waste package handling.

- ***Risks associated with electrical rooms***

The technical rooms required for the process are located in the surface facilities and in the underground facility, particularly in the cross cuts between the ramps and the drifts. This concerns compartmented rooms housing low-voltage main distribution boards, high-voltage range A and B (HVA, HVB) power supplies, transformers, inverters and communications and security systems (CFI). There are risks of fire outbreaks in these rooms, which can lead to the loss of equipment important for protection.

2.2.2.3 Measures to prevent the outbreak of fire

One of the main principles of the fire baseline applicable to Cigeo's design is based on limiting the fire load in facilities, selecting materials, equipment and cables, taking into account the fire resistance class limiting or even prohibiting the use of products with fast kinetics, and handling equipment design.

<u>Construction and development materials</u>

Usual provisions are made concerning the construction and development materials, with high performance classes in terms of fire resistance. Any wall liners used in the underground drifts must be at least class A or B.

Among the provisions taken into account, the following are to be indicated: use of the concrete material, absence of wood or wooden pallets, absence of materials with rapid kinetics, etc.

<u>Prevention of risks of electrical or static electricity origin</u>

The electrical power supply cables and conductors of the facility have characteristics of fire resistance equivalent to "C1 not releasing halogen compounds".

Management of fuel materials

Management of combustible materials is based on provisions for limitation of fire load, separation and isolation of these loads. The following main points are taken into account:

- In relation to the limitation of the fire load:
  - ✓ the ramp transfer system, due to its design, intrinsically limits the fire load at the ramp. Its on-board fire load is relayed to the machinery of the ramp transfer system at the surface – itself reduced by use of a direct-drive motor without an oil-bath gear motor);
  - ✓ use of self-propelled electrical carts on rails intrinsically limits the fire load in the connecting drifts and access drifts. The carts and shuttles have provisions for limiting and separating fire loads, mainly through the use of oils that are not readily flammable or even non-combustible where possible; fire can also be limited by allowing a distance between electrical boxes and cabinets and reinforcing their closure system;
  - ✓ ILW-LL casks have a very low fire load. HLW casks and HLW pusher robots produce a low fire load that is perfectly controlled;
  - ✓ the ventilation plant is located at the surface; no fan is present in the underground drifts in operation;
  - ✓ the fire load in the shaft is reduced.

An initial estimation of fire loads for the main items of equipment, performed at the basic engineering design stage, is presented in Table 2.2- below.

Table 2.2-11 *Order of magnitude of fire load for main items of equipment used for handling ILW-LL and HLW casks*

Equipment	Fire load
Turntable	1 650 MJ
Bottom cart	7 450 MJ
HLW Shuttle	5 720 MJ
HLW cask	3 650 MJ
Pusher robot cask	8 350 MJ
Pusher robot	1 700 MJ
ILW-LL shuttle	4 200 MJ
ILW-LL cask	Close to 0 MJ
ILW-LL docking facade	1 000 MJ
ILW-LL docking platform	1 000 MJ

- In relation to isolation of thermal loads:
  - ✓ in the surface facility, in the transport container unloading areas of the surface facility, the tractors of the transport vehicles are uncoupled and removed from the zone as much as possible;
  - ✓ the underground zones in operation are isolated and independent of the underground zones in construction work;
  - ✓ the electrical rooms are isolated from the process zones of the surface nuclear facility. In the underground part, the electrical rooms are in cross cuts or in dedicated niches. No electrical cabinets are present in the underground drifts;
  - ✓ in the ramps and underground drifts, the electrical conductors are positioned in sheathing in the invert. When cable trays are present in the effective section of the drifts and ramps, and if there is a safety challenge associated with the cables concerned, they are isolated and protected from fire;

- ✓ the ramp transfer system traction machinery and its maintenance equipment is located at the surface (ramp head) and isolated from the top station (smoke dampers closed, taking into account the difficulties relating to the passage of ramp transfer system cable);
- ✓ the various items of handling equipment for casks and HLW pusher robots maintain a relative distance in operation and in parking in order not to accumulate their fire load for the reference fire scenarios;
- ✓ the handling cell is isolated from the usable part of the ILW-LL disposal cell by the radiation protection door, which is closed, except for the period of time necessary for the bridge crane or stacking cart to pass. Although this shielded door is not smokeproof, it nevertheless constitutes a heat shield between the handling cell and the usable part of the disposal cell;
- ✓ at the bottom, the handling equipment for the ILW-LL disposal packages presents provisions for limiting and distancing fire loads in relation to the waste packages. The fire load of the stacking crane is located above the waste packages thus reducing the impact in the event of an accident.

2.2.2.4 Provisions for detection and fire response operations

In accordance with the defence-in-depth principle and regulations, facilities shall be monitored to ensure that any fire outbreak is detected as early as possible, to prevent it spreading and to extinguish it rapidly.

<u>Fire detection and associated safety devices</u>

This is based on:

- automatic fire detection systems in ambient conditions of rooms or drifts and located as close as possible to the potential fire sources, for example the sensitive electrical cabinets;
- additional fire detection devices installed, if necessary, in electrical cabinets for equipment contributing to the nuclear process for conditioning waste packages, transferring packages and placing them in the disposal cell, including mobile equipment (carts, shuttles, stacking crane);
- the vigilance of operating and maintenance personnel who will be trained and informed;
- a fire safety system able to relay fire alarms to the central safety station and the control room;
- voice communication devices for communication with the central safety station and the control room are present in the nuclear zones in operation (surface and bottom);
- a video-monitoring system allowing visual inspection of the fire alarm zones, upstream of the process of ambiguity resolution, engaged by the emergency teams and by the operating personnel trained for this task;
- evacuation or safety messages can be transmitted to personnel by an alarm system.

Fire detection in the ILW-LL disposal cells is ensured:

- in the stacking crane or stacking cart equipment;
- upstream of HEPA filtration;
- in the ambient conditions of the handling cell and if necessary in handling cell equipment.

<u>Emergency response and firefighting equipment</u>

Emergency response and firefighting equipment available for mitigation purposes includes:

- mobile safety equipment (extinguishers, etc.) adapted to the risks;
- fixed or on-board extinguishing systems;
- an emergency response group with a trained operational firefighting organisation;
- fire networks at the surface and underground;
- firefighting vehicles;
- extinguishing chemicals recovery systems.

Fixed or on-board fire-extinguishing systems are as follows:

- in the surface nuclear facility:
  - ✓ parking areas used by trucks for unloading transport containers are protected by suitable safety equipment if it is decided not to uncouple the tractor and remove it from the area;
  - ✓ in shielded cells: presence of fixed extinguishing system or of diffusers supplied by the emergency services;
  - ✓ the control room, computer room and the rooms contributing to information processing are protected by an extinguishing system.
- in the ramps and connecting drifts and access drifts:
  - ✓ the electrical or hydraulic cabinets and boxes located on the handling and transfer equipment presenting a significant fire load hold an autonomous automatic fire-extinguishing system. This provision, in particular, concerns the ramp transfer system and the cask transfer carts and shuttles.
  - ✓ the electrical cabinets are located in dedicated technical rooms. An automatic extinguishing system protects each electrical cabinet that requires it, including, if necessary, the volume inside the electrical room, including the false floor and false ceiling.
- in the handling cells and ILW-LL disposal cells:
  - ✓ a fixed expanding foam extinguishing system is specified in the handling cell, with a possibility of resupply from the access drift.
  - ✓ the cabinets and housings of the stacking carts and cranes hold an autonomous extinguishing system.

<u>Emergency response teams and operational firefighting organisation</u>

Emergency response and firefighting teams are on site with a station located in building 194 in the ramp zone.

The first and second emergency response teams are called in from the start of the alert.

Emergency response teams operate throughout the INB. Members are on duty round the clock.

The next levels of emergency operations are ensured by reinforcements within the site, then by calling in external teams (SDIS 55 and 52).

When the disposal sections are extended, to ensure ambiguity resolution in the event of a fire alarm, the first and second emergency response teams (mainly operating personnel) will be trained in ambiguity resolution. When operators are present at the bottom, the mobilisation of these operating teams by the Central Safety Station at the same time as the emergency response team may, in some cases, reduce the time taken for ambiguity resolution or for the first response.

- ***Firefighting systems***

Cigeo has firefighting systems: one in the ramp zone and another in the shaft zone. Each firefighting system of the site is composed of three tanks with a minimum volume of at least 120 m3 and three boosters with a normal electrical power supply backed up by a generator. Provision is made for a volume of 240 m3 to take into account maintenance work on a tank or booster.

A network of hydrants strategically positioned close to emergency access points runs along the boundary of EP1 and the boundary of shaft zone exits.

Dry risers serve the inside of the EP1 surface nuclear facility with hydrants inside the facility and supply connections outside at the vehicle track level.

The ramp site network supplies the underground nuclear operating zone. This involves a linked network deployed from both the waste package and service ramps. The underground firefighting system ensures a simultaneous flow rate of 120 m3/h for 2 h.

Emergency equipment is specified within the facility. This equipment is for use by emergency response teams.

- ***Fire vehicle***

A Cigeo fire vehicle is in the process of being defined. It covers the requirements of the whole of the site and incorporates the specific characteristics of the operation in an underground environment. This fire vehicle is designed to transport emergency response personnel with their equipment, and other emergency equipment. The width of the vehicle and its turning radius are defined to be consistent with the dimensions of the drifts and cross cuts that it can travel along. A dedicated garage for parking this vehicle is specified in the operating ZSL.

- ***Recovery of extinguishing agents***

The water from the fire extinguishing is managed and collected as close as possible to the location of the accident.

In EP1, a system for collection and retention of extinguishing water is planned for each room.

In the ramps, the extinguishing water is collected using gravity and stored at the foot of ramps (collection trench for the service ramp and buffer tank for the waste package ramp).

The underground drifts and the ZSL incorporate a collection trench in the invert. Floor drains are present every 10 to 12 metres to collect the fire extinguishing water. Access is provided to insert a lift pump into the lower section of each trench section.

In the handling cell of the ILW-LL disposal cell, the extinguishing agents are collected and stored by gravity then pumped out.

<u>Access and passage ways</u>

The EP1 surface nuclear facility is served on three sides and by access points in the roof.

Fire hydrants are installed close to the access points for emergency services and emergency equipment is available within the facility (in the stairways and passages). These provisions allow emergency response teams in the building to have access to the emergency equipment.

Access and manoeuvring areas for fire and emergency services and the implementation of emergency equipment are designed and arranged to ensure that emergency vehicles are unimpeded. For this reason, the areas concerned will have the following characteristics:

- minimum width, excluding parking strips: 3.50 metres;
- internal turning radius: 11 metres with, in the bends with internal radius R lower than 50 metres, an extra width defined by the equation: S = 15/R;
- clear height: 3.50 metres;
- maximum slope: 15%;
- load-bearing capacity: calculated for a vehicle of 130 kilonewtons (40 kilonewtons on the front axle and 90 kilonewtons on the rear axle, with a distance of 4.50 metres between them).

The underground zone has different specific provisions:

- the main developments are cross cuts between tubes that allow personnel to take shelter from smoke and allow the emergency services to operate from a protected zone, with each drift having a pedestrian route; single-tube drifts are equipped with protected routes;
- access for emergency response vehicles is through the different drifts, using, when necessary, cross cuts large enough to allow a fire vehicle through;
  emergency response operations in the underground operating zone are implemented from the operating logistics support zone (ZSL) and do not require connection with the construction zone (physical separation).

- ***Ramps***

The waste package and service ramps are interconnected at least every 400 m by cross cuts protected against smoke. The waste package ramp has a pedestrian path. The service ramp also has a pedestrian passage way and a road that can be used by the fire vehicle.

- ***Operating logistics support zone (ZSL)***

The shaft lifts can be used for emergency response (priority call system) and for evacuation of personnel. An emergency recess can be used for personnel to assemble and be sheltered. This emergency recess can be accessed via a linked network from the VFE shaft, the HLW and ILW-LL sections, the construction ZSL and the service ramp via an airlock.

- ***Connecting drifts of the HLW0 and HLW1/HLW2 sections***

The connecting drifts of the HLW0 and HLW1/HLW2 sections consist of three parallel tubes. The operating connecting drifts have a pedestrian path allowing evacuation in both directions. The evacuation/emergency connecting drifts and the connecting drifts are interconnected at least every 400 m. The evacuation/emergency connecting drift and the cross cuts are protected from smoke by applying overpressure between them and the connecting drifts. Due to the presence of an evacuation/emergency connecting drift, the HLW0 and HLW1/HLW2 connecting drifts do not present any particular vulnerability in terms of evacuation and emergency response.

- ***Access drifts for HLW0 and HLW1/HLW2 sections***

The twin-tube access drifts for the HLW0 and HLW1/HLW2 sections interconnected at least every 400 m by cross cuts protected from smoke. These cross cuts are all accessible to fire vehicles.

These drifts have a pedestrian path allowing evacuation in both directions, including in the presence of a shuttle and its cask.

The access of the fire vehicle from the evacuation/emergency connecting drift to the zone in the fire alarm requires operating constraints such as sufficient space between the equipment present at the same time in each tube and the possibility of controlling the movement of a shuttle in the unaffected tube. These requirements therefore allow the fire vehicle to use the cross cuts to reach the fire zone.

- ***ILW-LL connecting drifts***

These twin-tube drifts are interconnected at least every 400 m by cross cuts protected from smoke. These cross cuts are all accessible to fire vehicles.

These drifts have a pedestrian path allowing evacuation in both directions, including in the presence of a cask. Airlocks (with shelter function) are present in the two operating/construction interfaces at the end of the connecting drift.

The fire vehicle access from the operating ZSL to the fire alarm zone requires clearing access to fire using a cross cut as necessary. For this purpose, provisions are made so that a cart can move after a fire alarm has been triggered and clear the access.

- ***ILW-LL access drifts***

These shorter drifts provide access to the docking wall and the handling cell. They are accessible via the connecting drifts. They have a shelter located at the end of the drift at the docking wall.

- ***Handling cell and ILW-LL disposal cell***

The handling cells and ILW-LL disposal cells are classified as a prohibited zone in terms of radiation protection as soon as a disposal package is present. In the handling cells, routine maintenance operations are necessary. In the event of a fire, the shelter located in the access drift is accessible if evacuation is not possible.

- ***ILW-LL air return drift***

The air return drifts are single-tube drifts. They have a protected path integrated in the single tube providing a pedestrian path protected from smoke. Doors providing access to the protected path are located at the required intervals and are placed close to the filtration and electricity rooms.

airlocks (with shelter function) are present in the operating/construction interfaces of the air return drifts.

2.2.2.5 Provisions to prevent a fire from spreading and limit its consequences

The paragraph structure is the same as that of Section IV of the Order of 20 March 2014 on fire-related risk management in basic nuclear installation (32).

Compartmentation

The provisions concerning compartmentation are described in detail below. For this reason, the conventional fire considered corresponds to the cellulosic fire in the standard NF EN 13501 (formerly ISO 834). It is also considered for the thermal design of equipment.

Compartmentation provisions are made in a first approach to identify rooms or groups of rooms with a substantial potential fire load that can be mobilised and likely to threaten hazardous substances and/or radioactive materials and/or elements important for protection (EIPs).

These sensitive rooms or groups of rooms will be covered in the detailed design phase (APD) to refine the special provisions for detection, prevention and protection.

All the fire sectors provide at least a compartmentation time of REI 120.

- ***Surface nuclear installation***

Conventional technical rooms with major sources of fire and/or containing a potential major fire load that can be mobilised (for example electrical rooms, technical drifts, maintenance room for casks and "machinery" room for ramp transfer system) are compartmented

The rooms containing hazardous substances and/or radioactive materials able to be mobilised by a fire and likely to trigger a release and containing a potential major fire load that can be mobilised are classified as fire compartments. Depending on the potential consequences, one or more containment sectors may, where applicable, be installed around the edge of this room or groups of rooms.

Concerning the fire scenarios and studies considered, the compartmentation considered at this stage of studies is presented in Table 2.2-.

Table 2.2-12 Fire compartmentation planned for rooms in the surface nuclear facility

Room/Geographical zone	Identification of risk	Compartmentation options considered
Technical rooms	Major sources of ignition and a high available potential fire load	Fire compartments
Train/truck unloading and rooms receiving transport containers		Fire zone
Unloading ET-Vs/C5 inspection/placing in CtS	Hazardous substances and/or radioactive materials that can be mobilised by a fire and likely to trigger a release	Shielded cell covered as a Fire Zone. Front/Rear zones covered as a Containment Sector.
package conditioning facility buffer zones		Room in concrete structure. For the ILW-LL CPs sensitive to an increase in temperature, a fire performance is provided by the non-sealed ILW-LL CtS (cover on).
ILW-LL CS conditioning cell		Shielded cell covered as a Fire Zone. Front/Rear zones covered as a Containment Sector.
HLW CS conditioning cell		Shielded cell covered as a fire compartment including Front/Rear Zones
ILW-LL deconditioning cells		The shielded cell is covered as a fire compartment including Front/Rear Zones. A containment sector includes the fire compartment.
HLW deconditioning cells		The shielded cell is covered as a fire compartment including Front/Rear Zones
Cask storage area and process corridors to building at head of waste package ramp		Room in concrete structure. A fire resistance is provided by the ILW-LL and HLW casks.

- ***ILW-LL and HLW casks***

The cask envelopes are protected from the effects of a fire by the presence of thermal protections in the containment and at the door giving a performance of EI 120.

- ***Ramps***

Cross cuts, recesses and electrical rooms in cross cuts between the waste package ramp and the service ramp are fire compartments. Fire qualification REI 120 (standard NF EN 13501) concerns fire resistance, thermal isolation in fire, but also smokeproofing.

- ***Top station***

The top station is isolated from the surface facility by an airlock with fire qualification of at least REI 120 (standard NF EN 13501). The ramp transfer system traction machinery and the service rooms (maintenance, electrical rooms, etc.) are also isolated from the waste package ramp under normal operating conditions by a smoke door.

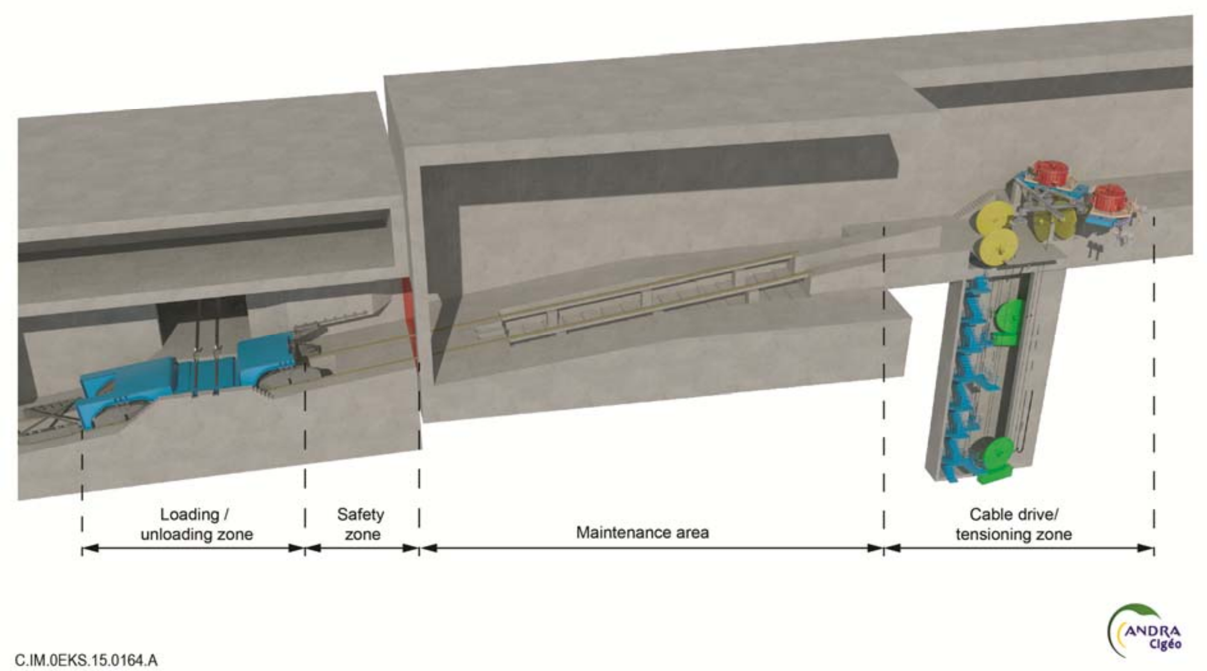

Figure 2.2-1 Layout of top station

- ***Bottom station***

The bottom station of the ramp transfer system has a mobile smoke curtain that limits the spread of smoke along the rest of the waste package ramp in the event of fire at the bottom station.

- ***Operating logistics support zone (ZSL)***

The rooms in the Operating ZSL are fire compartments (see Table 2.2-).

Table 2.2-13 Fire compartmentation planned for the Operating ZSL

Rooms	Fire compartmentation at least REI 120 under conventional fire
Vehicle room	Presence of major fire load associated with the vehicles Protection of rooms with important functions for evacuation of people and operations by emergency teams.
Advanced Control Station	Protection of room with important functions for evacuation of people and operations by emergency teams.
Emergency recess	The emergency recess is considered to be a shelter and is therefore characterised by a fire resistance
Technical rooms providing process support (disposal of equipment, storage of casks, operating waste, etc.)	All of these rooms are compartmented.

- ***Connecting drifts and ILW-LL and HLW access drifts***

Cross cuts, recesses and electrical rooms are fire compartments.

HLW cell closing devices are covered with a fire resistance of EI 120.

As part of limitation of the risk of propagation of smoke in the underground facility, the drifts are compartmented over a maximum length of 800 m. This compartmentation (RE 120 for the structures and EI 60 for the doors) is applied to all drifts, including the two ILW-LL air return drifts. The presence of this compartmentation allows for evacuation of people in good conditions with regard to plausible fires linked with the type and fire loads of vehicles present in these zones.

- ***ILW-LL disposal cells***

The "handling cell + ILW-LL disposal cell" assemblies and the filtration room are covered as a fire compartment, with performance to at least REI 120.

The performance in terms of the leak rate in the docking wall combined with the reference fire in the handling cell or disposal cell, and the correct performance of the disposal package in case of fire, avoiding the need to install a containment sector on the access drift side, will be defined subsequently.

- ***Interfaces with construction zone***

The presence of physical separations between the operating zone and the construction zone in the ILW-LL and HLW connecting drifts and ILW-LL air return drifts ensures that these zones are independent under normal and accident operating conditions. In the event of fire, the function of these separations is to prevent propagation from one zone to another (see Section 2.5 on coactivity). The physical separations provide compartmentation of at least EI 120 under HCM.

Fire resistance of structures

- ***Surface nuclear facility EP1***

The structure of the train/truck unloading area is of the metal type. In order to prevent any fire scenario that may lead to the destruction of this structure on full transport containers in the waiting or unloading phase, the shunters and truck tractors cannot gain access to the area under this structure.

The EP1 support structures are made of reinforced concrete. They are stable under conventional fire (R 120) and the floors are stable for fire and fire-resistant (REI 120).

- ***Ramps and underground drifts***

The civil works of the drifts are stable to fire classification R 120 under conventional fire, including the duct under the arch. This provision limits the risk of drift wall liner being ruined by casks or emergency teams; it is applied to the entire underground facility in operation, including the ramps.

- ***Casks***

The bases and frames of the ILW-LL and HLW casks are R 120 under conventional fire.

The frame of the ramp transfer system vehicle forms part of the elements providing the stability of the casks. The frame is lowered on the rails in incident conditions. By design, it does not interfere much with cask stability and locking. Substantiation of fire resistance will be provided in a fire situation.

- ***ILW-LL disposal cells***

The civil works are designed to class R 120 in terms of stability in conventional fire conditions.

Ventilation – Smoke extraction

- ***Ventilation management in the surface facility (EP1)***

The provisions concerning ventilation management in a fire situation comply with the practices of basic nuclear installations. For the fire areas in shielded cells, the ventilation control procedure in the event of fire is as follows:

- close the air supply valve in the room on fire to stop the air supply;
- maintain extraction from this room for as long as possible, while monitoring extraction, in particular in the filtration system in the room;
- If extraction performance limits for the room are exceeded, (temperature upstream of filtration, pressure difference at filter terminals), shut down extraction from the room and switch to static containment;
- maintain ventilation in zones adjacent to the room on fire.

The stairways are protected from smoke by application of overpressure.

- ***Ventilation management in fire conditions on the ramp***

The ramps are ventilated mechanically in the upward direction under normal conditions. To facilitate evacuation and response, the following options have been retained:

- implementation of upward ventilation for smoke management in the event of fire, with extraction at the ramp head;
- maintaining an air speed in full section equal to the critical speed in order to ensure that there is no smoke returning upstream of the fire in the air flow direction;
- ventilation mode for each ramp is the same in nominal conditions and fire conditions.

- ***Ventilation management in fire conditions at the top station***

The top station is ventilated mechanically from the waste package ramp (the ramps are ventilated mechanically in the upward direction in nominal conditions).

To facilitate evacuation and response, the following options have been retained:

- closure of doors between building EP1 and the top station preventing smoke going through;
- extraction of smoke performed at ramp head.

- ***Ventilation management in fire conditions at the bottom station***

The bottom station is ventilated mechanically using the ventilation of the underground drifts.

To facilitate evacuation and response, the following options have been retained:

- closure of doors between the operating ZSL, the connecting drifts and the bottom station preventing smoke going through;
- implementation of a smoke extraction network at the bottom station.

- ***Ventilation management in fire conditions in an underground drift (HLW and ILW-LL sections and Operating ZSL)***

The underground drifts are vulnerable with regard to the risk of an under-ventilated fire developing, spreading particularly toxic fumes, and a risk of a thermal phenomenon associated with incomplete combustion.

A fire in the underground facility drifts is managed by closing the doors through each zone to create a compartment, and by implementing a smoke extraction system associated with this compartment.

This compartment is compatible with the class of containment of underground drifts of type I/C1. It does not require any reversal of air flow direction. The control of the ventilation comes from control actions to be performed in the control room and the PCS.

Preference is given to simple, robust ventilation system operating principles. The options considered for underground drift ventilation are as follows:

- maintaining negative pressure cascades in the facilities;
- limiting actions and changes required when switching ventilation between nominal conditions and fire conditions as follows:
  - ✓ not changing the operating point of cross cut boosters between nominal and incident conditions;
  - ✓ installing overpressure valves on cross cut walls to passively guarantee overpressure regulation in cross cuts, and protected routes if the doors are closed;
  - ✓ installing a by-pass between the transfer and return air shafts to avoid the need to change fan operating points between nominal and incident operating modes;
- overpressure in adjacent cross cuts in the event of a drift fire;
- containing smoke by installing a compartmentation system no longer than 800 m in the connecting and access drifts of the HLW section and in ILW-LL connecting drifts;
- installing a smoke management system, with hatches installed at average intervals of 100 metres along the different connecting drifts and access drifts with compartments;
- implementing a longitudinal fresh air intake inside the compartment on fire, using an air transfer opening installed at each compartmentation door. This air transfer opening can be closed again if operational conditions require;
- limiting changes in ventilation operating mode when switch to the incident/accident operating mode for a more reliable and robust ventilation system.

- ***Ventilation management in a fire situation in an ILW-LL connecting drift***

In the event of a fire breaking out in an ILW-LL connecting drift, the ventilation control procedure is as follows:

- close the fire dampers at the fresh air intake of the handling cells to shut down the air intake for all the ILW-LL disposal cells;
- check that the docking facade and access airlock to the handling cell are closed;
- open the bypass between the air supply shaft and the air return shaft to recover the flow rate associated with the supply to the ILW-LL disposal cells for which the air intake has been shut down;
- shut down extraction in the ILW-LL disposal cells using the fire damper closing control located at the extraction outlet of each disposal cell;
- for all cross cuts between ILW-LL connecting drift: switch off the boosters taking air in from the affected drift and switch on those located on the side of the unaffected, smoke-free drift;
- close the partition doors of the compartment on fire;
- open the smoke control hatches in the compartment on fire;
- close the hatches/dampers located at the end of the connecting drift;
- open the air transfer opening located at the compartmentation door positioned upstream of the compartment on fire.

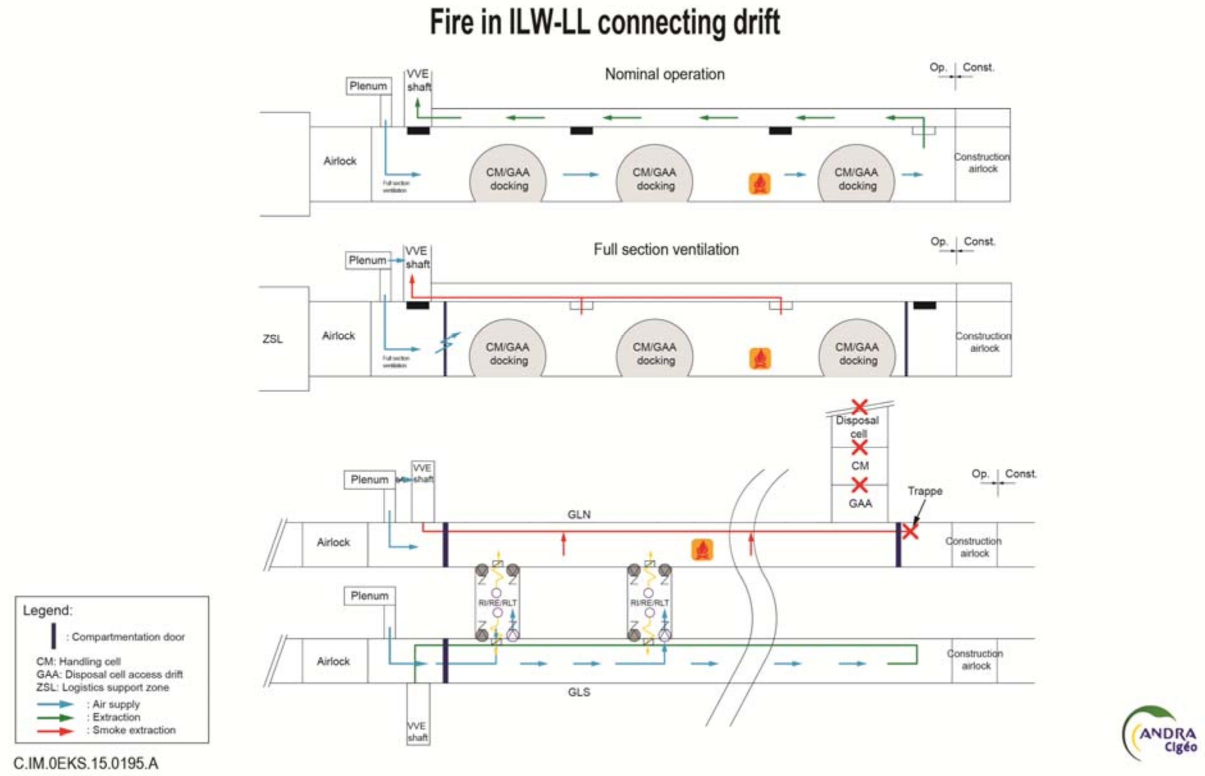

Figure 2.2-2 *Potential fire management in an ILW-LL connecting drift*

- ***Ventilation management in a fire situation in an ILW-LL access drift***

Given their short length in relation to connecting drifts, ILW-LL access drifts do not require compartmentation or a specific ventilation system. Fire management in this type of drift is similar to that adopted for the connecting drift. The hatches of the connecting drifts ensure smoke extraction in the event of a fire in the access drift.

- ***Ventilation management in a fire situation in a handling cell of ILW-LL disposal cell***

Fire management in a handling cell or ILW-LL disposal cell is different from fire management in a drift because of the presence of disposal packages that are not protected in a cask. For these rooms, stopping the air supply and maintaining extraction take priority as long as the integrity of the HEPA filters at the end of the disposal cell allows it.

When a fire breaks out in a handling cell or an ILW-LL disposal cell, ventilation control procedure is as follows (in chronological order):

- closure of the docking facade if not already closed;
- closure of the shielded door between the handling cell and the disposal cell if it is not already closed;
- closure of the fire damper(s) located at the air intake of the handling cell via an automatic or controlled action;
- monitoring parameters associated with the HEPA filters of the cell (filter clogging, filter upstream temperature, filter downstream smoke detection);
- closing the extraction fire damper on:
    - ✓ reaching high temperature upstream of filters,
    - ✓ reaching the filter clogging threshold,
    - ✓ detection of smoke downstream of the filters.
- static containment of the disposal cell.

- ***Ventilation management in a fire situation in an ILW-LL air return drift***

The general principles for ventilation management in the event of fire are identical to those mentioned in the event of fire within an ILW-LL connecting drift.

A separate duct on the ILW-LL return manifold and dedicated to smoke extraction is planned for the air return drift.

The specific characteristics of the air return drifts concern:

- the presence of a protected routing in the air return drift;
- the presence of filtration rooms (DNF of cells) containing the filtration housings of the ILW-LL disposal cells;
- the presence of evacuation/ emergency response cross cuts between the construction zone and the operating zone.

- ***Ventilation management in a fire situation in an HLW connecting drift***

The general principles are similar to those shown for the management of a fire in the ILW-LL connecting drifts.

The specific characteristics in the HLW connecting drifts are:

- the presence of an emergency evacuation drift in overpressure compared with the connecting drift;
- the presence of a cross cut to transfer the cask from the West HLW access drifts to the East HLW access drifts.

In the event of fire breaking out in an HLW connecting drift, the ventilation control procedure is as follows:

- close compartmentation doors of HLW access drifts;
- switch off extraction in the HLW access drifts located upstream of the fire in the air flow direction via the extraction shutters located at the bottom of the drift;
- for cross cuts located between the emergency evacuation drift and the affected compartment, open the powered isolation dampers located between the cross cut and the emergency evacuation drift;
- close the partition doors of the compartment on fire;
- open the smoke control hatches in the compartment on fire;
- close the hatch/extraction damper of the HLW access drifts located in the direction of air flow downstream of the affected compartment;
- open the air transfer opening at the compartmentation door located upstream of the fire.

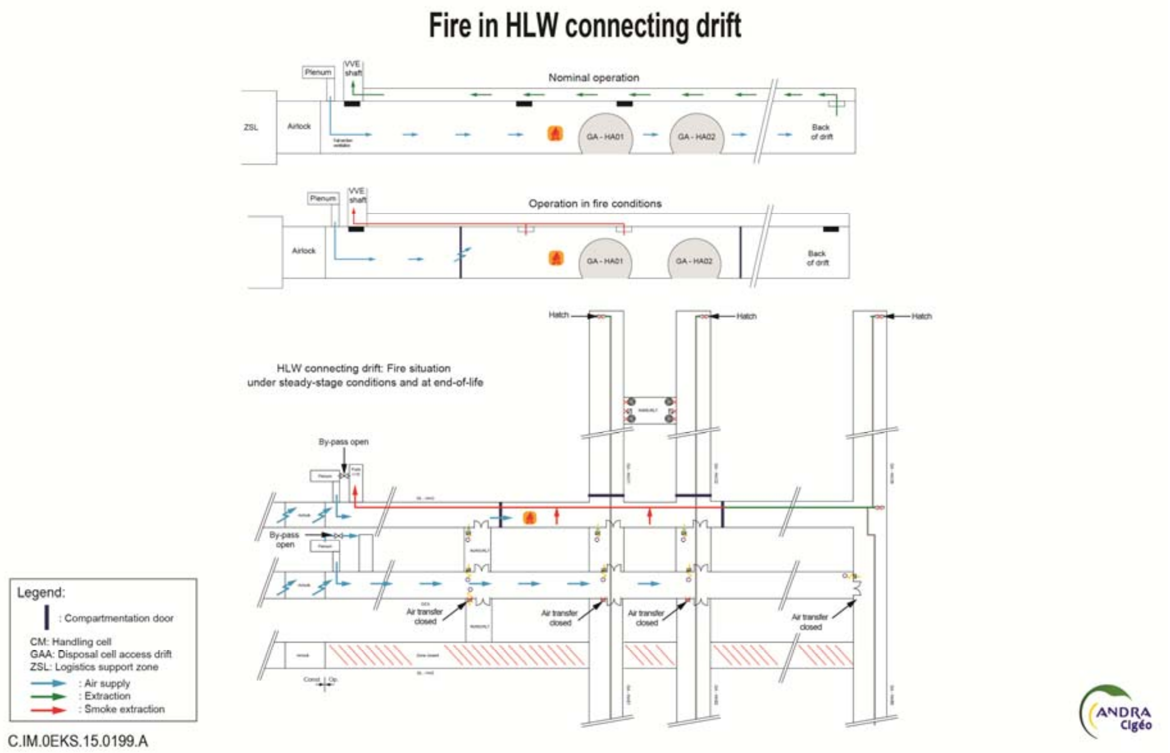

Figure 2.2-3 Potential fire management in an HLW connecting drift

- ***Ventilation management in a fire situation in an HLW access drift***

The general principles are similar to those shown for the management of a fire in the HLW connecting drifts.

In the event of fire breaking out in an HLW access drift, the ventilation control procedure is as follows:

- close the partition doors of the compartment on fire;
- for cross cuts located within the affected compartment, switch off the boosters taking air in from the affected drift and switch on those located on the unaffected smoke-free drift side;
- open the smoke control hatches located in the compartment on fire;
- close the hatch/extraction damper located at the end of the unaffected then affected access drift
- open the air transfer opening at the compartmentation door located upstream of the fire in the direction of air flow.

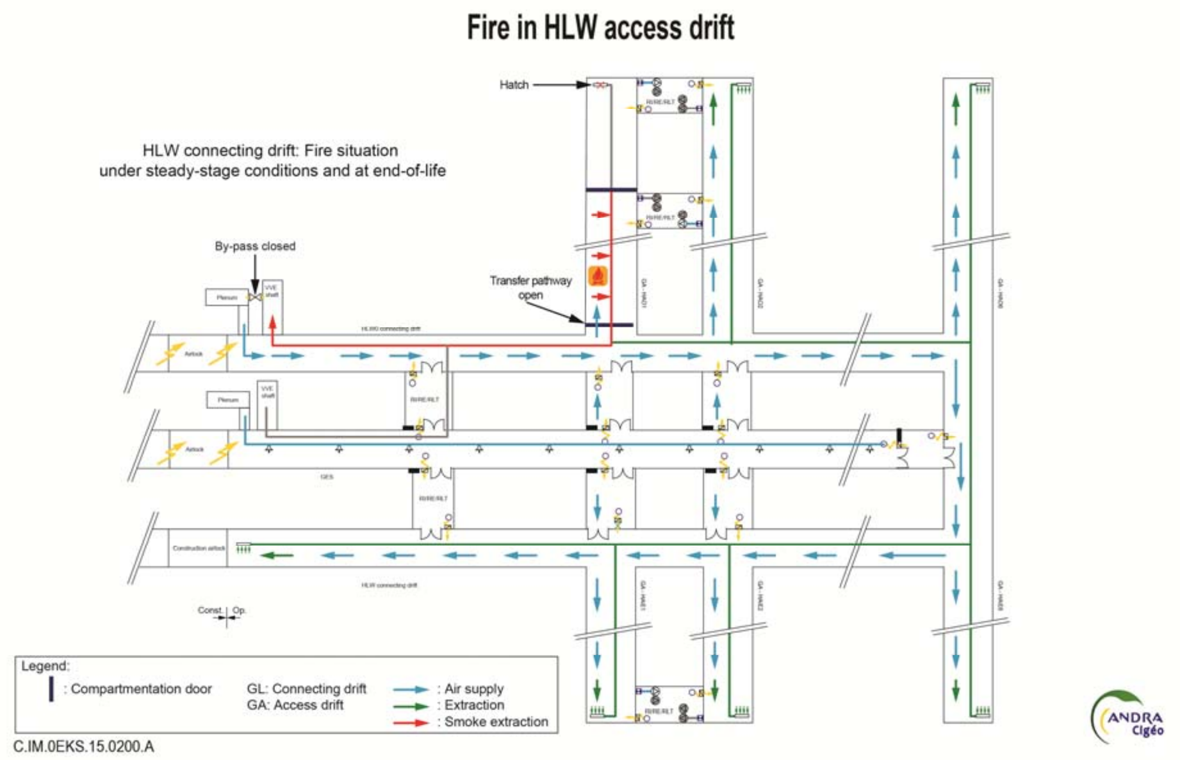

Figure 2.2-4 Potential fire management in an HLW access drift

- **Management of ventilation in a fire situation in a cross cut or a technical room**

The ventilation control procedure is as follows:

- close the fire dampers located in the air supply and the air extraction from the room by means of the CMSI or a thermal fuse;
- close the doors in the room or cross cut;
- switch off the relay fan if necessary.

In the event of fire in a connecting or access drift, the ventilation system of the interconnections and technical rooms located in the cross cuts is shut down and the associated fire dampers are closed.

<u>Control devices</u>

In the surface nuclear facility, the control devices are remote-controlled from the PCS on the CMSI, with manual controls available on the equipment.

In the underground drifts, the doors of the airlocks, compartments and cross cuts are remote-controlled to allow the fire vehicle through. Manual control is also possible.

In connection with the PCS, it is planned to be able to control movement of an HLW shuttle or of a cart in the unaffected tube upstream of the operation from the control room.

The valve controls are accessible and operable by the emergency services (in addition to remote control from the PCS).

2.2.2.6 Identification of operating conditions

Based on the analysis of risks of fire and the defence-in-depth provisions that are implemented, scenarios arising from various operating conditions are identified and shown in the tables below.

The scenarios are classified in accordance with the defence-in-depth provisions (or barriers) that must be withdrawn in order to trigger the unwanted event according to the methodology shown in Volume I.

<u>Incident conditions</u>

The incident conditions are concerned with a postulated fire outbreak that is detected (automatically or by personnel) and for which action (automatic extinguishing, level 1 response) can be taken to extinguish the fire before it spreads.

Design-basis accident conditions

Table 2.2-14 Design-basis accident conditions associated with the risk of fire

	Room/zone	Scenario	Main defence-in-depth provisions	
			Levels 1 & 2	Level 3
Surface	Train/truck unloading area	Fire on shunter or truck or rail lorry involving an ET	Inspection and periodic tests No parking of shunters or tractors in the area Spacing of shunter and ET Limiting fire loads in the area Automatic fire detection (DAI) at unloading site	Obligation to uncouple the trailer from the tractor or otherwise installation of appropriate emergency equipment Fire qualification[58] of a B-type ET (800°C, 30min) Intervention by site emergency teams
	Receiving area 3 for horizontal transport containers	Fire on truck or rail lorry involving an ET	Inspection and periodic tests No parking tractors in the area Presence of automatic fire detection and suppression systems on rail lorry Automatic fire detection in the room	Obligation to uncouple the trailer from the tractor or otherwise installation of appropriate emergency equipment Intervention by site emergency teams
	Vertical transport container receiving area	Fire on rail lorry involving an ET	Inspection and periodic tests Limiting fire load Presence of automatic fire detection and suppression systems on the rail lorry Automatic fire detection in the room	Fire qualification of a B-type ET (800°C, 30 min) Static containment of room Intervention by site emergency teams
	ET preparation and docking hall, transfer carriage corridor	Fire on cart, transfer carriage, involving ET	Inspection and periodic tests Limiting fire load Transfer cart equipped with automatic fire detection and suppression systems Automatic fire detection in the room	Fire qualification of a B-type ET (800°C, 30 min) Static containment of room Fire compartmentation Intervention by site emergency teams
	Cell for unloading waste packages from transport containers	Fire on cart transporting the primary package	Inspection and periodic tests Limiting fire load Transfer cart equipped with automatic fire detection and suppression systems Automatic fire detection in the room	Fire compartmentation Dynamic and static containment of the cell Intervention by site emergency teams
	CP inspection cell	Fire on cart and primary package inspection equipment	Inspection and periodic tests Limiting fire load Transfer cart equipped with automatic fire detection and suppression systems Automatic fire detection in the room	Fire compartmentation Dynamic and static containment of the cell Intervention by site emergency teams
	Cell for placing CP in disposal container	Fire on equipment supporting disposal package	Inspection and periodic tests Limiting fire load Transfer cart equipped with automatic fire detection and suppression systems Automatic fire detection in the room	Fire compartmentation Dynamic and static containment of the cell Intervention by site emergency teams
	ILW-LL or HLW conditioning cell	Fire on cart and on equipment of a conditioning station with an unprepared disposal package	Inspection and periodic tests Limiting fire load Transfer cart equipped with automatic fire detection and suppression systems	Fire compartmentation Dynamic and static containment of the cell Intervention by site emergency teams

[58] Provision taken from transport regulations

	Room/zone	Scenario	Main defence-in-depth provisions	
			Levels 1 & 2	Level 3
			Automatic fire detection in the room	
	"Process" movement corridors	Fire on cart, on transfer carriage with primary package or disposal package	Inspection and periodic tests Limiting fire load Transfer cart equipped with automatic fire detection and suppression systems Automatic fire detection in the room	Fire compartmentation Dynamic and static containment of the room Fire resistance of packages/fire resistance test for CS4 containers Intervention by site emergency teams
	HLW or ILW-LL cask loading cell	Fire on shuttle, turntable and MLL involving cask	Inspection and periodic tests Limiting fire load Transfer cart equipped with automatic fire detection and suppression systems Automatic fire detection in the room	Fire compartmentation Dynamic and static containment of the cell Fire resistance of packages/fire resistance test for CS4 containers Intervention by site emergency teams
	Ramp transfer system top station	Fire on shuttle and ramp transfer system cart involving the cask	Inspection and periodic tests Limiting fire load Transfer cart and ramp transfer system equipped with automatic fire detection and suppression systems Automatic fire detection in the room	Fire compartmentation Dynamic and static containment of the room Fire resistance of the cask Fire resistance of packages/fire resistance test for CS4 containers Intervention by site emergency teams
LSF	Waste package ramp	Fire on ramp transfer system cart involving the cask	Inspection and periodic tests Limiting fire load Transfer cart equipped with automatic fire detection and suppression systems Automatic fire detection in the ramp	Fire resistance of the cask Fire resistance of packages/fire resistance test for CS4 containers Ventilation control Intervention by site emergency teams
LSF	Service ramp	Fire on maintenance vehicles or dedicated transfer equipment	Inspection and periodic tests Limiting fire load Presence of automatic fire detection and suppression systems on vehicles Automatic fire detection in the ramp	Ventilation control Intervention by site emergency teams
LSF	Cross cuts	Fire in a technical room	Inspection and periodic tests Limiting fire load Automatic fire detection and emergency equipment in the cross cut	Fire compartmentation Static containment of room Intervention by site emergency teams
Bottom	Ramp transfer system bottom station	Fire on underground cart and on ramp transfer system cart involving the cask	Inspection and periodic tests Limiting fire load Transfer cart and ramp transfer system equipped with automatic fire detection and suppression systems Automatic fire detection in the room	Fire compartmentation Ventilation control Fire resistance of the cask Fire resistance of packages/fire resistance test for CS4 containers Intervention by site emergency teams
Bottom	Connecting drifts	Fire on underground cart at bottom and on turntable involving the cask	Inspection and periodic tests Limiting fire load Underground cart equipped with automatic fire detection and suppression systems Automatic fire detection in the drifts	Fire compartmentation Dynamic and static containment of the room Fire resistance of the cask Fire resistance of packages/fire resistance test for CS4 containers Intervention by site emergency teams

	Room/zone	Scenario	Main defence-in-depth provisions	
			Levels 1 & 2	Level 3
	Access drifts	Fire on underground shuttle involving the cask	Inspection and periodic tests Limiting fire load Transfer cart and ramp transfer system equipped with automatic fire detection and suppression systems Automatic fire detection in the drifts	Fire compartmentation Dynamic and static containment of the room Fire resistance of the cask Fire resistance of packages/fire resistance test for CS4 containers Intervention by site emergency teams
	Cross cuts between drifts	Fire in a technical room	Inspection and periodic tests Limiting fire load Automatic fire detection and emergency equipment in the cross cut	Fire compartmentation Dynamic and static containment of the room Intervention by site emergency teams
	Operating ZSL	Fire in a technical room, or a maintenance vehicle	Inspection and periodic tests Limiting fire load Presence of automatic fire detection and emergency equipment	Fire compartmentation Dynamic and static containment of the room Intervention by site emergency teams
	ILW-LL handling cell	Fire on equipment in the cell (lift table, stacking crane, etc.) involving a disposal package	Inspection and periodic tests Limiting fire load Presence of automatic fire detection and suppression in ILW-LL handling cell Automatic fire detection in the room Permanent fire suppression system	Fire compartmentation Dynamic and static containment of the room Fire resistance of packages/fire resistance test for CS4 containers Intervention by site emergency teams
	ILW-LL disposal cell	Fire on stacking crane during transfer of a disposal package	Inspection and periodic tests Limiting fire load Presence of automatic fire detection and suppression in ILW-LL handling cell	Fire compartmentation Dynamic and static containment of the room Fire resistance of packages/fire resistance test for CS4 containers Intervention by site emergency teams
	Cell	Fire in the pushing actuator during transfer of disposal package	Inspection and periodic tests Limiting fire load Monitoring faults from SCC	Fire resistance of waste packages

Design-basis accident conditions for PUI

Table 2.2-15 PUI design-basis conditions associated with the fire risk

	Room/zone	Scenario	Main defence-in-depth measures
Surface	Cell for unloading, C5 inspection and placing in disposal container	Fire on the cart and on the equipment of the C5 inspection station involving a primary package with failure of the on-board detection and extinguishing system combined with failure of the room automatic extinguishing system	Fire compartmentation Dynamic and static containment of the cell Containment sector Intervention by site emergency teams
Bottom	ILW-LL disposal cell	Fire on the stacking crane involving a disposal package with failure of the on-board fire-extinguishing system combined with a failure of the disposal container	Performance of the disposal container Fire compartmentation Dynamic and static containment of the cell Stability in fire of the crane and the structure of the disposal cell

Excluded situations

Table 2.2-16 Main excluded situations associated with the fire risk

	Room/zone	Scenario	Main defence-in-depth provisions
Surface	Train/truck unloading area	Fire on shunter or truck in area affecting the waste packages present in the ET	Prohibition of shunter access in the area Distancing shunter from ET Obligation to uncouple the trailer from the truck or otherwise installation of appropriate emergency equipment
	Receiving area 3 for horizontal transport containers	Fire on truck in receiving area affecting waste packages present in the transport container	Prohibition of access to tractor in the area Obligation to uncouple the trailer from the truck or otherwise installation of appropriate emergency equipment

	Room/zone	Scenario	Main defence-in-depth provisions
	Unloading cell, C5 inspection and placing in CtS	Fire on the bridge crane due to spillage of burning oil from motor and gears at the ET unloading station or at the station for placing in disposal container with risk of damage to waste package	design of gears and motors preventing oil flow Retentions under gears and motors of the bridge crane
LSF	Exhaust air extraction shaft (VVE)	Fire in the shaft	Absence of fire load

2.2.3 Risk of explosion

As with the fire risk and the risk associated with the radiolysis of waste producing hydrogen, the risk of explosion requires the presence of an explosive product, a fuel and a source of ignition.

2.2.3.1 Source of risk

The potential risks of explosion for Cigeo are associated with:

- the hydrogen produced by the batteries of the electrically-powered transport systems;
- the presence of combustible products necessary for certain operations. These operations are not defined precisely at this stage. At this stage of design, use of acetylene cylinders is considered for welds and use of organic solvents for the needs of the analysis laboratory or the operating process.

The rooms of the various facilities that, based on the solutions considered at this stage, present potential risks of emission of explosive gases are shown in Table 2.2-.

Table 2.2-17 Location of rooms/equipment that may present a risk of explosion in the various Cigeo facilities at the current stage of studies

Location	Identification of equipment with a risk of explosion
Surface facility	Analysis laboratory: explosion following a leak of organic solvent (acetone or ether type)
	Operating process: • Explosion following a leak in an acetylene cylinder during the welding or cutting operations • Explosion following a leak of organic solvent (acetone type) or detergent (diluted) used in the maintenance workshops
Surface-bottom transfer facility	Technical cross cuts (battery charging rooms): explosion of a cloud of hydrogen during battery recharging
	Service ramp: explosion of a vehicle battery following ignition of the hydrogen release
	Upstream station/downstream station: explosion of vehicle batteries following ignition of the hydrogen release
	Cask rooms at ramp head: explosion of fuel products/welding gas cylinders
Underground facility	Handling cell: Explosion of fuel products
	ILW-LL access drift: explosion of fuel products/gas cylinders

2.2.3.2 Preventive measures

The preventive measures taken against the risk of explosion consist mainly in controlling at least one of the necessary conditions required for an explosion to occur (quantity of combustible substances involved, concentration of combustible material in the air, source of ignition).

The main provision identified at the current stage of studies concerns:

The provisions made on the Cigeo site regarding the risks of explosion associated with hydrogen released by batteries, are as follows:

- using recombination batteries or batteries that release little hydrogen;
- performing an ATEX analysis in accordance with the regulations in force and setting up ATEX zoning where necessary;
- placing batteries on vehicles in casings to keep them at a distance and isolate them from sources of ignition;
- the ventilation that limits the concentration of combustible vapours or gases in the air in surface or underground facility rooms below explosive limits.

The provisions made regarding the risks of explosion associated with solvents and potentially explosive products, are as follows:

- giving preference to products that are not explosive or only slightly explosive and limiting the quantities used;
- setting up ATEX zoning;
- installing ventilation to limit the concentration of combustible vapours or gases in the air.

2.2.3.3 Monitoring systems

The main monitoring provisions associated with identified risks of explosion are as follows: keeping track of potential changes in ATEX zoning on the site by updating, at least once a year, the document on protection against the risks of explosion and installing hydrogen detectors, particularly in rooms used for charging the batteries of the different equipment.

2.2.3.4 Mitigation measures

The main measure implemented to mitigate the impact of an explosion is to ensure that zones presenting a risk of explosion are at a distance from targets identified for protection, in particular waste packages to prevent the risk of dissemination and, in general, any equipment fulfilling a safety function. Where applicable, these targets are to be protected by addition of an explosion-resistant shield.

2.2.4 Risks associated with the loss of electrical power supply

2.2.4.1 Source of risk

Loss of electrical power supply may be due to:

- internal failures of the electrical power supply (failure of distribution equipment, etc.);
- external hazards (earthquake, flooding, weather conditions, aircraft crash, etc.);
- internal hazards (fire, handling, etc.).

The consequences associated with the loss of electrical power supply are:

- direct loss of the function provided by a receiver (ventilation, monitoring, etc.) ;
- inappropriate response from a receiver (untimely opening of a door, release of a load, etc.).

Loss of electrical power supply is therefore likely to generate risks in the facility (risks of handling, fire, etc.) as well as loss of protective functions. This analysis focuses on the impact of a loss of electrical power supply on the various receivers and defines the action to be taken to maintain the facility in a safe state in the event of loss of electrical power supply.

2.2.4.2 Functions affected by the loss of electrical power supply

Risk analyses (in particular see Section 2.1, 2.2.1 and 2.2.2) have identified the main functions and systems/equipment affected by a loss of electrical power supply, i.e.:

- ventilation systems providing in particular:
  - ✓ dynamic containment;
  - ✓ removal of radiolysis gases emitted by the waste packages in the ILW-LL disposal cells;
  - ✓ conditioning the atmosphere in the rooms;
  - ✓ clean-up of rooms/cells;
  - ✓ control of smoke in the underground drifts in the event of fire;
- handling equipment, which must mainly:
  - ✓ secure the load;
  - ✓ eliminate any untimely movement;
  - ✓ limit decelerations;
- the systems/equipment that contribute to static containment including fire compartmentation (openings, docking device, valves, etc.);
- monitoring equipment, in particular:
  - ✓ radiological monitoring in rooms and at outlets;
  - ✓ temperature monitoring in rooms;
  - ✓ hydrogen concentration monitoring;
  - ✓ monitoring filter head loss;
  - ✓ fire detection;
- automatic fire detection system;
- safety lighting in particular the evacuation routes (shelters, safety recesses, etc.).

2.2.4.3 Preventive measures

The risk of loss of electrical power supply is prevented by the distribution architecture which guarantees different levels of power supply reliability according to the function performed by the various receivers.

At this stage of the studies, facility power supply design is based on;

- a normal power supply provided by the RTE grid, consisting of two independent and redundant power supply lines at least up to the level of the 90 kV/20 kV transformer substations (normal network);
- an emergency power supply provided by generators (normal network backed up);
- inverters capable of maintaining continuous power supply to certain receivers.

The systems/equipment for which loss of the electrical power supply may lead to inappropriate responses do not necessarily require a more reliable electrical power supply. Constructive provisions are put into place to limit the risks (for example, to limit the risk of untimely opening of a radiation protection door or release of load, mechanical locking is put into place, etc.).

The design and dimensioning of the electricity distribution take into account:

- compliance with applicable standards;
- installation of electrical protections of power supply lines and equipment;
- equipment maintenance;
- redundancy and independence (physical and electrical) of main equipment of electrical network (transformers, busbars, electrical cabinets, power supply cables, at least when they are on the emergency-supplied network);

- independence of redundant power supply lines thus eliminating common modes in the event of a hazard or electrical fault, through an electrical and/or physical separation.

In the event of loss of normal power supply, the emergency power supply ensures the continuity of electrical power supply for the following systems/equipment:

- the ventilation system, in particular for ILW-LL disposal cells;
- the monitoring system, in particular:
  - ✓ outlet monitoring;
  - ✓ hydrogen concentration monitoring;
  - ✓ monitoring filter head loss;
- the automatic fire detection and extinguishing system;
- safety lighting;
- main bridge cranes.

2.2.4.4 Monitoring systems

The faults of the various electrical networks are monitored using a system used for:

- monitoring sources, feeders, insulation faults;
- monitoring electrical networks;
- management power sources;
- consumption information;
- voltage measurements;
- real-time transmission of alarms to supervision;
- saving alarms;
- diagnostics;
- ensuring uninterrupted services.

2.2.4.5 Mitigation measures

In the event of total loss of electrical power supply (normal and backed-up):

- the handling equipment has design provisions to shut down the process in a safe state, i.e.:
  - ✓ installation of fail-safe devices such as power-off brakes (MLL, shuttles, carts, ramp transfer system) and irreversible lifting systems (MLL, shuttle, cart, stacking crane/truck);
  - ✓ the brakes implemented on the various items of equipment are designed to eliminate any deceleration greater than 1g;
  - ✓ the lifting equipment secures the load and includes a manual load lowering function;
  - ✓ the openings and casks are designed to eliminate any movement or any untimely closure;
- shutting down the ventilation does not comprise facility safety. In this situation:
  - ✓ the containment of the cells and rooms remains provided by a static containment;
  - ✓ concerning evacuation of radiolysis gases, the risk remains under control for a period of 5 weeks (see Section 2.1.5);
  - ✓ there is no impact on the control of the risk associated with thermal releases (see Section 2.1.4).
  - ✓ monitoring of the facility is provided (see Section 2.2.4.2) because the fire detection and alarm systems remain powered by inverters for the time taken to restore the electrical power supply.

At this stage of studies, the provisions applied in the event of loss of electrical power supply make it possible to rule out any risk of losing an important protective function.

2.2.5 Risks associated with the loss of fluids

2.2.5.1 Loss of compressed air

The loss of the compressed air supply may be due to failure of compressors or a hazard on the power supply circuits (earthquake in particular).

At the ILW-LL docking facade

Compressed air is used to inflate the seals, ensuring continuity of static containment when the cask is docked at the ILW-LL docking facade.

The loss of compressed air at the ILW-LL docking facade makes the following impossible:

- inflating the seals of the ILW-LL docking facade, i.e. making a seal between the cask and the facade or between the facade door and the facade or between the cask door and the facade door;
- actuating the pneumatic actuation of the cask docked at the ILW-LL docking facade, i.e. locking or unlocking the cask door.

In the event of loss of air supply at the ILW-LL docking facade, the facade is jammed in the cask docked or undocked position. However, there is no loss of containment.

Provisions are made to restore normal operating conditions:

- if a cask is docked, the cask can be unloaded and the disposal package placed in in the disposal cell before the compressed air supply for the facade is restored;
- if the loss of supply occurs during docking of the cask, it can be removed from the facade in order to perform the corrective maintenance operations. Also, the locking and unlocking of the cask can be performed manually.

Pressure sensors are installed in the branch connections for the docking facade. Regular inspections of these items of equipment are to be performed in order to prevent the risk of failure during performance of the process.

In the HLW cell

Compressed air is used for inflation of the seals on the pusher robot in order to make contact with the HLW cell.

The loss at the pusher robot level leads to loss of seal adhesion on the HLW cell and consequently causes the robot to stop. It does not compromise the safety of the facility and has no impact on the safety functions.

In the event of loss of compressed air supply for the pusher robot, the pusher robot is removed from the cell. The operating plug is then replaced by the pusher robot cask (this action requires no use of compressed air) with no human intervention near the opening. During these operations, the HLW disposal package that was being disposed of remains in position in the cell. The disposal operation will be able to resume when normal operating conditions are restored.

Pressure sensors are installed on the compressor for the pusher robot. Regular inspections of these items of equipment are to be performed in order to prevent the risk of failure during performance of the process.

2.2.5.2 Loss of water supply

The "firefighting water supply" is necessary for fighting any fire likely to occur at the facility. The firefighting water supplies are composed of several water tanks (main, emergency, etc.). They can be supplied from two sources (distributor water and recycled water).

Firefighting equipment includes, among others, two firefighting systems that are interconnected. They serve the surface facilities of the ramp zone and of the shaft zone, the surface-bottom connections and the underground facility. The supply of pressure and flow into the underground facility is implemented by gravity.

In the event of loss of the water supply from a tank or a network, the other means of supply, tanks and network are used to maintain the function.

2.2.6 Risks associated with the loss of ventilation

2.2.6.1 Source of risk

The ventilation network is composed of air supply and extraction fans, ducts and filters with the last filtration level (DNF) and check valves.

The loss of ventilation or reduction of its performance may result from:

- internal failures of the ventilation network, particularly the failure of air supply and extraction equipment;
- external or internal hazards that could lead to failure of equipment or degradation of its performance (e.g. partial obstruction of air intakes, damage to network equipment).

Ventilation contributes to achievement (directly or indirectly) of safety functions of the facility, in particular:

- the dynamic containment of certain rooms ensuring management of pressures;
- the conditioning of the atmosphere in order to regulate the temperature in relation to fresh air and to ensure that ambient conditions are kept compatible with correct operation of the items of equipment required for safety purposes;
- removal of radiolysis gases in the ILW-LL disposal cells.

Nuclear ventilation in the underground facility also provides a comfort function for the personnel.

2.2.6.2 Functions affected by the loss of ventilation

Risk analyses (see Section 2.1.1) have identified the main functions and systems/equipment affected by a loss of ventilation.

<u>Consequences of loss of ventilation in relation to risks of dispersion of radioactive materials</u>

In normal operation, no contamination is expected in any Cigeo rooms/zones. Only the ILW-LL disposal cell operating range takes account of the possibility of limited contamination. The nuclear ventilation installed ensures dynamic containment for accident operating conditions (in the event of a breach of containment of the packages). It limits the risk of dispersion and purifies rooms by collecting radioactive materials suspended in the air.

In the event of loss of the ventilation in normal operation, a static containment provided by the walls of the rooms and the HEPA filter of the ventilation system is sufficient to keep the facility in an acceptable condition including in ILW-LL disposal cells.

Consequences of loss of ventilation in relation to risks associated with the heat of the packages

In normal operation, the ventilation has no safety role in relation to removal of heat released by the waste packages (see Section 2.1.4.3). Therefore, the loss of the ventilation, with regard to the risk associated with the heat of the packages, has no consequences for safety for either the surface facility or the underground facility. The ventilation in the underground facility, in particular for the HLW zone, provides a comfort function for personnel (maintaining ambient air temperature compatible with working conditions).

Consequences of loss of ventilation in relation to radiolysis

Analysis of the risk associated with the radiolysis of waste has identified the times taken to reach an H_2 concentration of 3% (75% of the LEL) for sensitive rooms in the event of loss of the ventilation (see Section 2.1.5.3):

- 23 weeks for the ET-V unloading cell (room with shortest time taken in the surface facilities);
- 5 weeks for ILW-LL disposal cells.

Given the time taken to reach an H_2 concentration of 3% in the surface facility, the loss of ventilation has no consequences for the safety of the facility.

For ILW-LL disposal cells, in the event of loss of the ventilation, provisions will be made in order to restore ventilation before 5 weeks. This period ensures a safety margin regarding the risk of explosion associated with radiolysis (when hydrogen concentration reaches 4%).

2.2.6.3 Preventive measures

As a rule, the following general provisions are applied in design and operation of the ventilation network:

- compliance with standards of design of the various items of ventilation equipment;
- quality of design of equipment;
- preventive maintenance of ventilation equipment.

The ventilation networks for the surface facility and the underground facility are separate and independent. It should be noted that the construction zone also has independent ventilation.

The architectures for the ventilation systems are designed in relation to the consequences associated with loss of ventilation, particularly through the following provisions:

- redundancy and independence of certain equipment (extractors, HEPA filters including DNF);
- redundancy of the electrical power supply;
- design for earthquake and for other external hazards as necessary;
- protection against fire for certain ventilation system equipment.

Constructive provisions are applied to ensure correct operation of the ventilation system, in particular in relation to external hazards:

- protection of the fresh air intake against extreme weather conditions;
- the location and positioning of the air intakes to protect against the external fire risk and the risk of tornadoes/strong winds;
- the location of the ventilation equipment off ground (raised) and the high position of the fresh air intakes (in relation to the risk of flooding).

2.2.6.4 Monitoring systems

The monitoring systems installed are used to check ventilation system performance and keep track of parameters related to ventilation. They are used for:

- monitoring air intake;
- monitoring negative pressure cascades;
- monitoring air flow rate at various points in the facility;

- monitoring the positions of fire dampers and check valves;
- detecting equipment shutdown or faults.

2.2.6.5 Mitigation measures

In normal operation, the loss of ventilation does not compromise facility safety. The containment function will be controlled by shutting down and placing in safe conditions, valves used for isolating rooms and therefore maintaining of static containment.

Mobile emergency fans installed on site ensure that the ventilation system can be reconfigured within a defined time, in particular for ILW-LL disposal cells regarding the radiolysis risk. An extended loss of ventilation in ILW-LL disposal cells longer than five weeks is therefore eliminated (redundancy and design for internal and external hazards of the ventilation, monitoring devices, preventive maintenance and mobile emergency fans).

Given the provisions made, in the event of loss of ventilation, the protection functions are controlled.

2.2.7 Risks associated with the loss of monitoring

2.2.7.1 Source of risk

Radiological monitoring is provided by various items of equipment, installed over the whole of the facility, used as follows:

- on one hand to check irradiation levels and atmospheric contamination in rooms; these checks provide data to the workers and may generate feedback data for access to certain rooms (shielded doors);
- on the other hand to monitor releases into the environment by taking various samples, in particular at the outlets; these checks can be performed in real time (with uploading to the radiation control panel) or at a later date through periodic examination.

As radiological monitoring plays a key role in the defence-in-depth of the facility, its loss could constitute a risk:

- of exceeding radiation thresholds (irradiation or contamination), due to a lack of information for the workers;
- of loss of atmospheric release monitoring.

Loss of monitoring may be caused by:

- an internal failure of the radiological monitoring equipment;
- a loss of electrical power supply;
- a loss of instrumentation and control of equipment;
- an internal or external hazard for the equipment.

2.2.7.2 Preventive measures

In general, the preventive measures associated with the risks related to loss of monitoring are:

- the redundancy of the main measuring equipment and networks allowing data to be transmitted;
- the electrical power supply for the equipment using inverters allowing for continuous power supply in the event of loss of electrical power supply;
- installation of sensitive equipment in fire compartments in the facility.

2.2.7.3 Monitoring systems

A radiation control panel on the central control room (when necessary relayed to the local control stations) allows for relaying of all signals concerning the various items of monitoring equipment; loss of an item of equipment is indicated immediately by recording a fault.

These alarms are used to trigger the appropriate actions during identification of a discrepancy with regard to normal operation.

Locally the radiation protection monitors are also equipped with colour coding used to identify their operating status.

2.2.7.4 Mitigation measures

Limitations of consequences concerning loss of radiological monitoring as a result of specific actions:

- as soon as a radiation protection monitor is identified as non-operational, actions for evacuation of personnel and for physical lockout/tagout of the rooms concerned are put into place with shutdown of the process;
- In the event of loss of monitoring of releases, the process is shut down for the time it takes to restore function.

2.2.8 Risks associated with the loss of instrumentation and control

2.2.8.1 Source of risk

In general, the risk of loss of instrumentation and control concerns the loss or failure of the Cigeo industrial information system described in Chapter 3.6 of Volume II which constitutes a network architecture that providing the following, in particular:

- nuclear process instrumentation and control functions that incorporate the handling equipment for primary packages and disposal packages;
- the functions of the various communications and security systems incorporating, in particular, radiation protection, nuclear ventilation, fire safety systems and nuclear material management.

The risks associated with the loss of instrumentation and control are the loss of data transmission or the loss of control of certain functions that could generate risks for safety:

- either through direct loss of the function provided by the item of equipment (e.g. loss of ventilation in the event of loss of an item of instrumentation and control equipment for ventilation, such as the automatic controller),
- or by incorrect reaction of a component or software application (e.g. untimely or incorrect opening of a shielded door).

The loss of instrumentation and control may be associated with:

- an internal failure of the equipment forming the industrial information system (network, automatic controllers, servers, etc.);
- a loss of electrical power;
- an internal or external hazard threatening these items of equipment.

2.2.8.2 Preventive measures

In general, the provisions made for the industrial information system, to prevent any loss of instrumentation and control for the nuclear process and more generally for the various communications and security systems are:

- use of a highly resilient high-availability network;
- use of safety automation for sensitive functions for the safety of the facility;
- redundancy of certain components of the infrastructure such as:
  - ✓ the servers that constitute common modes with respect to the different functions;
  - ✓ control stations with installation, in certain cases, of local control stations;
  - ✓ means of communication, in some cases, using wireless technologies;
  - ✓ the automation for the equipment whose instrumentation and control is sensitive or the safety of the facility (nuclear ventilation, ramp transfer system, etc.);
- the robustness of the equipment forming the network infrastructure, in relation to different hazards, in particular fire resistance, leaktightness, resistance to local radiation levels for during periods of time appropriate with Cigeo operations;

- the integration of test and qualification programmes for the functions associated with instrumentation and control, also during gradual activation of the various parts of the underground facility;
- location of special equipment for training the operators to use the industrial information system.

2.2.8.3 Monitoring systems

Various alarms on the automatic controllers of equipment and more generally at various levels of infrastructure make it possible to upload information during loss of industrial information system equipment.

These alarms are used to trigger the appropriate actions during identification of a discrepancy with regard to normal operation.

2.2.8.4 Provisions for limitation of consequences

In the event of a loss of instrumentation and control, the following provisions are made to limit the consequences, depending on the type of equipment:

- installation of hard-wired logic designed, for automatic devices controlling sensitive equipment, to maintain the functions necessary for placing equipment into a safe state;
- implementation of active or passive mechanical devices enabling security locking during loss of instrumentation and control (fail-safe brakes, mechanical locking of certain handling beams, etc.).

2.2.9 Risks associated with internal flooding

2.2.9.1 Source of risk

The risks of internal flooding are associated with the presence, within the perimeter of the nuclear facilities, water supply networks, systems for collection of liquid effluent and hydraulic fluid contained in the equipment. This risk can also come from liquid effluents coming from the fire-extinguishing systems as well as the tanks and basins of the fire-extinguishing system.

A failure or a hazard on these networks or equipment may lead to the occurrence of a leak, overflow or break in containers that could lead to internal flooding that can remain localised in the event of a leak or spreading occurring in a closed network (limited capacity) or be generalised in the event of a hazard occurring in an open network (unlimited capacity) or following large-scale hazard (earthquake, etc.) that might involve a several separate networks at the same time.

At this stage of studies, the main sources identified that are likely to generate internal flooding are:

- Water supply networks:
  - ✓ heating hot water, chilled water and demineralised water networks (surface facility);
  - ✓ firefighting water network (underground facility[59]);
  - ✓ cooling network (underground facility);
- The liquid effluent collection networks:
  - ✓ collection of water seepage (underground facility);
  - ✓ collection of potentially contaminated effluents (surface facilities);
  - ✓ collection of fire-extinguishing water (surface and underground facilities).

2.2.9.2 Preventive measures

The main preventive measures applied in relation to the risk of internal flooding are as follows:

- networks designed to take into account the physico-chemical characteristics of the fluids contained (temperature, acidity, pressure, etc.), supplemented by a regular inspection and preventive maintenance programme;
- networks routed and/or protected to limit risks of mechanical hazards.

2.2.9.3 Monitoring systems

The main monitoring measures adopted regarding the risk of internal flooding are as follows:

- detectors of pressure or flow rate are installed on the fluid network;
- flooding probes are placed in sumps or containers and level measurements are installed on the tanks;
- regular monitoring patrols by operators.

2.2.9.4 Mitigation measures

The main mitigation measures implemented regarding the risk of internal flooding are as follows:

- installation of shutoff valves on controllable networks on detection of sudden variation in pressure or flow rate,
- placement of tanks in containers appropriate for their volume,
- trenches used for recovery of any effluents with sumps dimensioned to the maximum volume of effluents able to be leaked.

2.2.10 Risks associated with emissions of hazardous substances

An emission of hazardous substances, i.e. chemical and/or toxic substances within the basic nuclear installation would be likely to lead to damage of equipment (corrosion) and/or toxic releases outside the installation.

At this stage of the studies, the approach adopted for analysing the risks of emission of hazardous substances has not identified any risk that could compromise the safety of the facilities. The sources identified within the nuclear facilities are not likely to generate emissions that could have an impact on the Safety targets as well as on human health or the environment.

The principle applied at this stage is that no toxic, harmful or corrosive elements will be present in the immediate environment of the waste packages (the operations where these products are involved are performed with no waste packages present).

[59] For the surface facility, the firefighting water network is composed of dry risers inside the building.

2.2.11 Risks associated with flying projectiles and with pressurised equipment

Flying projectiles may be the consequence of a failure of an element turning at high speed, an element under pressure or an explosion.

2.2.11.1 Source of risk

The equipment presenting a risk of flying projectiles is:

- the electrical and thermal motors used, for example for bridge cranes
- rotating machines (reel type….) equipped with material protection;
- ramp transfer system cable guide rollers;
- fans.

The equipment showing a risk of failure of an item of equipment under pressure are:

- hydraulic units used, for example, to send the liquids present in the underground facility up towards the surface;
- fire extinguishers;
- the accumulators of the safety brake units for the ramp transfer system;
- cask shock absorbers;
- "high-pressure" pipes for distribution of compressed air necessary for operation of tools used in the mechanical workshops.

At this stage of design, the rooms containing equipment whose failure presents a potential risk of flying projectiles are shown in Table 2.2-.

Table 2.2-18 Location in Cigeo facilities of items of pressurised equipment or equipment with a potential risk of flying projectiles at the current stage of the studies

Location	Pressurised equipment and/or equipment for which a failure can generate a risk of flying projectiles
Surface facility	Fire extinguisher burst.
	Fan room: flying projectiles following a blade rupture
	Maintenance workshop: flying projectiles following a failure on the rotating machinery (reels, drills…).
	Pump room: flying projectiles following the failure of moving equipment at the pump.
Surface-bottom transfer facility for waste packages	- Fire extinguisher burst - Break in ramp transfer system cable guide roller - Burst on a fire extinguishing system on board transfer equipment, - Burst in the hydraulic system used on transfer systems, - Break in pressurised pipes/channels at the ramp, cross cut or top and bottom stations of the waste package ramp.
Underground facility	Fire extinguisher burst.
	Break in pressurised pipes/channels in ILW-LL and HLW connecting and access drifts, technical cross cuts or air return drifts.
	Compressed air storage room in ZLS: break in a tank or a compressed air cylinder.

2.2.11.2 Preventive measures

At this stage, the preventive measures presented are generic. These provisions will change when the equipment and their location is defined more precisely as part of detailed engineering design (APD). The provisions are mainly concerned with application of standards in force for the design and dimensioning of the equipment.

2.2.11.3 Monitoring systems

The main provisions concern the monitoring of operating parameters of the equipment (for example, the power of the fans) and the visual inspection of the equipment particularly during maintenance operations.

2.2.11.4 Mitigation measures

At the current stage of the studies, the main provisions of protection in relation to the risks of flying projectiles and of failure of pressurised equipment are generic. They will be adapted when the design of the equipment and its locations will be defined more precisely. These general provisions concern:

- distance of rotating machinery such as fans, with respect to packages, casks and transport containers;
- the presence of roller correction on the ramp transfer system equipment;
- the presence of anti-whip devices on pressurised pipes that present a risk for safety equipment or personnel;
- installation of protection on rotating parts of machinery (fan motor, etc.) to prevent projections;
- wearing of safety equipment in the event of intervention nearby.

2.2.12 **Risks associated with ageing**[60]

2.2.12.1 Source of risk

Ageing is the transformation or modification of a structure or item of equipment due to the effect of time passing or the conditions to which it is exposed. It is a normal and inevitable phenomenon, which may lead to increasingly frequent equipment malfunctions or faults, or even total failure preventing equipment operation.

The methods used to control ageing involve a combination of technical and organisational solutions:

- devices/equipment or materials adapted to wear or to the environment;
- maintenance/renovation operations.

Operating experience feedback shows that about fifty or so accidents have taken place since 1990 in various industrial sectors, according to BARPI. A technical assessment by the CSNI (33) proposes managing fuel cycle facility ageing. The principles for managing this phenomenon, and the best practices indicated in this technical assessment, are applied to Cigeo and presented in the next section.

2.2.12.2 Ageing management principles

This section describes the principles applied to manage equipment ageing. Three phases of life are defined.

<u>During design</u>

The strategy put into place during the design of a new facility consists in setting up a programme for management of ageing at the point at which structures, systems and components (SSC) are identified as important for safety, along with their required roles and performances.

[60] The design of certain equipment and structures must take into account the fact that Cigeo is designed to remain in operation for a hundred years or more. .

AS from design, the alteration of SSCs due, in particular, to the physical ageing mechanisms must be predicted and their consequences must be reduced, in particular considering the specific characteristics associated with the surface facilities, the underground structures and the zones that are accessible or not. This is achieved through the following steps:

- applying a rigorous and structured method to deal with ageing-related problems, taking into account all the available data; at this stage, relevant feedback from facilities and data from research programmes are widely used in the defined concepts and proposed provisions;
- identify, assess and take account of all potential ageing mechanisms for the equipment, whether active or passive;
- be sure to use materials with the best possible resistance to the foreseeable physical effects of ageing (materials with a high resistance to embrittlement under radiation, materials with low sensitivity to water, temperature, etc.);
- specify large enough safety margins in the design to take account of the effects of ageing;
- ensure that the design and layout of the equipment facilitate decontamination operations, routine testing, inspections, maintenance and replacements so that the ALARA principle can be followed during the interventions of personnel and the production of waste can be reduced to a minimum;
- reduce the number of items of equipment that cannot be subjected to routine testing and inspections or maintenance to a strict minimum;
- ensure that the design of the facility complies with the defence-in-depth principle by defining safety barriers that are able to reduce the consequences of foreseeable events;
- ensure that the operator's organisation makes provision for documenting the ageing management programme.

<u>During manufacturing, construction and commissioning</u>

During these three phases, the strategy will include:

- providing equipment manufacturers with relevant information concerning the factors associated with ageing management, in particular, operating limits and conditions;
- performing inspections to check that the equipment produced complies with the safety characteristics defined during design, taking ageing into account;
- setting up a technical documentation management system including records related to quality assurance and providing evidence of safety;
- when the facility is commissioned, identifying parameters likely to have an impact on ageing-related degradation (for example, intensity of ionising radiation) together with the corresponding acceptance criteria, then monitoring them throughout the facility's lifetime.

<u>During operation</u>

The strategy to be followed during operation is based on the implementation of an ageing management programme.

This ageing management strategy is divided into three categories:

- maintenance, preferably preventive (aimed at preventing equipment failure), or a regular procedure for early failure detection may be performed, to deal with ageing for easily replaceable equipment;
- an ageing management programme (identifying the characteristics that limit operating life) used for equipment not designed to be replaced (e.g. civil works, trenches, equipment in disposal cells);
- measures set up to ensure that spare parts are available for equipment that deteriorates rapidly (e.g. instrumentation and control, small electrical and electronic equipment).

A regular equipment testing and maintenance programme will be set up and implemented in accordance with the safety file (safety report, operating limits and conditions). A proactive approach should be adopted in favour of preventive maintenance rather than corrective maintenance of equipment.

Ageing management for instrumentation and control includes physical ageing, although the main problem is hardware and software obsolescence. Some examples of good practice are:

- systematic identification of the effective lifetime and planned obsolescence;
- preparation of a modification plan for replacement of obsolete equipment;
- obtain spare parts for the specified operational lifetime or find new suppliers;
- prepare complete and specific documentation for maintenance and replacement of equipment;
- ensure compliance with standards and rules;
- consider changes to equipment that is important for protection.

Facility ageing management also covers non-technical aspects, such as:

- human and organisational factors (management of knowledge through personnel training and renewal),
- collection of data and archiving (documentation management),
- assessment of means of management of ageing as well as the necessary equipment (human resources, financial means, tools and equipment and external resources).

Therefore, facility ageing management consists in ensuring that time has no impact on the safety level of the facility throughout its lifetime. This requires maintaining of safety functions by controlling technical ageing and managing the human and organisational aspects.

2.2.12.3 Preventive measures

The design requirements must provide for prevention of the risk of ageing of civil works, in particular nuclear surface facilities, surface-bottom connections and underground structures. These constitute the main barrier for preventing the risks associated with ageing. This involves:

- maintaining the integrity of the structures and transfer facilities, particularly to allow removal of disposal packages as part of the reversibility,
- limiting the deformation and deterioration of interfaces necessary for return to operation of the disposal structures,
- maintaining the functional clearances between disposal structures and disposal packages, in consideration of subsequent removal operations.

In order to prevent premature ageing of the facility and its components, the materials and their protection are chosen specifically during design. Corrosion-resistant materials, robust electrical systems (in order to prevent insulation faults and short circuits), specific coatings (paint, etc.) are prioritised.

In addition, a maintenance and monitoring schedule appropriate for the equipment designed will be defined on the basis of data capitalised during design and consolidated during operation: failure rate, average lifetime, foreseeable mechanisms for degradation to failure, issues.

<u>Surface nuclear installation</u>

Given the current theoretical operating lifetime of the nuclear surface facilities, two successive installations are planned, linked in particular with management of ageing: a facility named EP1 (lifetime of about 60/70 years) and another called EP2 (about the same lifetime). On this basis, there are no plans for renovation after 60 years on the civil works of these buildings.

Since basic nuclear installations (INBs) are subject to a ten-year review, the first renovation work will be considered after ten years. Major renovation works, based on duration of life of main items of equipment, are also considered at this stage:

- 20 years for renovation of instrumentation and control and developed electrical and electronic equipment;
- 30 years for equipment under particular mechanical or thermal stress (HLW packaging station, etc.);
- 40 years for major equipment such as carts, fans, etc.

Finishing work likely to require renovation work concerns paintwork and false ceilings every 10 years, joinery, hardware, sealing, flooring and signalling every 20 years.

<u>Underground structures and accessible equipment</u>

For the underground nuclear facility, the frequency for renovations is similar to that presented above for the surface facilities.

The ramps and drifts of the underground facility are continuously ventilated to maintain conditions that do not degrade structural concrete. Preventive maintenance and replacement operations are specified in particular for the following equipment: mechanical equipment, doors, pipes, electrical equipment and automatic controllers.

<u>Inaccessible structures and equipment</u>

Inaccessible structures and equipment concern the zones in which a continuous and definitive presence of radioactive waste is expected: mainly the disposal cells and disposal containers since the rooms of the surface facility may be cleared of packages for renovation operations. These inaccessible structures and equipment are and/or will be subject to a design with design margins offering a high degree of confidence regarding their reliability over the operating period considered.

The ageing of the running rails and their supports in the ILW-LL disposal cells is controlled by the initial design choices (choice of material, anti-corrosion treatment, extra thickness for wear, etc.) and the maintaining of favourable ambient conditions in the cell (absence of external hazards).

<u>Equipment in the nuclear process of transfer and disposal of packages</u>

The equipment in the nuclear process of waste package handling and transfer is subject to preventive maintenance in order to maintain its ability to perform its operational functions.

As an indicative and non-exhaustive example at this stage, some frequencies and operations for replacement of equipment likely to be subject to ageing effects are presented below:

- the shielded door of the ILW-LL disposal cells is subject to an inspection once a year (pulleys, cable, rollers, etc.) with replacement of parts depending on wear;
- the parts of the docking facades are inspected every year and are subject to preventive maintenance operations depending on wear; the seals of the cell door are changed every year;
- preventive maintenance on the turntables, running tracks and ramp transfer system varies depending on the components:
  - ✓ annual inspection of the general condition of the rails and of the whole of the ramp transfer system, the turntable structure, the spacing of the rails, the condition of the electric rails, the radiating cables and decking;
  - ✓ annual inspection of tightening torques of clamps, check for absence of leakage from firefighting equipment, geared motors and hydraulic containers;
  - ✓ inspection of the shape of the rails and of welds every two years;
  - ✓ inspection of the visual appearance and of welds of the beams and topographical survey of the rails every five years.

2.2.12.4 Monitoring systems

In addition to scheduled renovation and inspections performed as part of preventive maintenance (see previous section), monitoring provisions are made for detection of any premature ageing of the materials and equipment necessary for correct operation of the facilities.

In addition, from the start of operation, ageing analysis sheets will be prepared for monitoring of the equipment, based on the lifetime of the equipment as supplied by the manufacturer. Observing an increase in failure rates is an indicator of ageing that will be put into these analysis sheets and will make it possible to optimise preventive maintenance. Wear must also be measured systematically for the components and devices that are essential to safety and reliability.

The remainder of this section shows specific additional checks in the facilities and on equipment that is accessible and inaccessible. The equipment that provides or contributes to safety functions is also subject to special monitoring through management of EIPs and of monitoring devices shown in the last paragraph.

<u>surface nuclear facility, accessible underground structures and equipment</u>

The degradation of the concrete of the various structures (in particular in underground drifts) is detected visually during ten-yearly inspections.

The ramp transfer system cable is monitored regularly by means of magnetic particle inspections along its entire length.

<u>Inaccessible structures and equipment</u>

Degradation of the concrete in the various inaccessible structures (mainly the ILW-LL disposal cells) is detected visually during ten-yearly inspections, in particular using robotic video equipment allowing for inspection of the integrity of civil works.

Concerning the HLW cells that are not accessible in the presence of a disposal package, changes inside of the sleeve can also be monitored using robotic video equipment.

In addition, the monitoring programme set up for disposal cells and cells in the ILW-LL and HLW sections detects any changes, such as deformations or corrosion. These indicators take into account all expected and unexpected changes and therefore reflect component ageing.

Changes in disposal packages may be monitored either visually, using robotic equipment placed inside disposal cells, or after their removal, through branch connections in the ventilation system located downstream of the ILW-LL disposal cell, or by collecting air from the HLW disposal cell via the access drift.

Concerning equipment such as the rails of the stacking crane and their supports located in the ILW-LL disposal cell, these are inspected visually using robotic video equipment during the ten-yearly inspections. This frequency could be reduced depending on the results of the annual inspections performed on similar equipment located in the handling cell (see previous section).

<u>Detection of failures of containment and radiation protection</u>

The ageing phenomenon may take the form of degradation of the containment between two different containment classes, entailing a risk of dissemination of radioactive materials. Regarding the cask docking facades (at the surface and at the bottom), this would indicate a degradation of the containment between a C2 zone and a C1 zone. The most sensitive zones concern those that are in interface with the transport container unloading cell which is a C4 containment class. This risk is monitored by the radiological monitoring system installed, and in particular in relation to dissemination, by the presence of aerosol detectors.

This phenomenon can also lead to degradation of radiation protection in relation to the docking facades, cell penetrations and casks. This risk is monitored by the radiological monitoring system installed, in particular for external exposure monitoring, using gamma detectors.

2.2.12.5 Mitigation measures

Maintaining favourable ambient conditions with only slight variations helps limit the risk of premature ageing of structures, equipment and components. Furthermore, equipment that is sensitive to ionising radiation is protected (distance, screen, etc.) right from the design stage, to limit the effects of this radiation and reduce the risk of premature ageing.

In addition to the monitoring, preventive maintenance and renovation programmes, an effective organisational structure will be set up (trained personnel, procedures, spare parts, etc.) to ensure high-quality and prompt corrective maintenance following an equipment failure, fault or anomaly. This also helps to limit the effects of ageing.

Redundancy in the process (for example the lifting drive trains, the two electrical power supply lines and back-up network ...), in particular for the elements that are important for protection, is also an effective method of protecting against the consequences of random failures of equipment due to ageing.

2.3 External hazards

2.3.1 Risks associated with aircraft crash

2.3.1.1 Source of risk

The analysis of the aviation environment shows that the risk associated with aircraft crash needs to be taken into account. In accordance with the RFS-I.1.a, the analysis is performed for general, commercial or military aviation. The types of aircraft to be included are:

- the CESSNA 210 with a half span of 0.5 m, and the LEAR JET 23 with a half span of 5.5 m for general aviation;
- the AIRBUS A380 with a half span of 25 m for commercial aviation;
- the RAFALE with a half span of 5.5 m for military aviation.

Also, given the presence of a heliport on the site, an analysis of the risk of a helicopter crash is also performed.

The main consequences of an aircraft crash are the more or less localised destruction of the civil works of the surface facilities, which may entail a potential loss of the secondary containment system or affect the safety functions and the development of a fire associated with the presence of kerosene in the tanks.

The targets to be considered are those that may compromise the safety function "confining radioactive materials to prevent the risk of dispersion of these materials" (see RFS I.1.a), i.e.:

- buildings containing radioactive materials;
- rooms and equipment ensuring or contributing to the containment of radioactive materials.

The targets applied for the analysis therefore are:

- the surface process building, which contains the waste packages in particular;
- the exhaust air extraction shaft of the operating zone, in relation to availability of nuclear ventilation in ILW-LL disposal cells;
- firefighting water tanks in the ramp zone and shaft zone, with regard to fire risk management.

In accordance with RFS I.1.a, a crash probability assessment was carried out for each of the targets identified and for each aircraft category, and the results compared with the objectives given in RFSI.1.a, namely:

"*The goal is that the overall probability of a workshop being the source of unacceptable releases should not exceed 10^{-6} per year.*

For this purpose, a category of hazard sources associated with three types of aircraft (…) should be taken into account in the design of the workshop if the probability that it might be the cause of unacceptable releases is greater than 10^{-7} per year".

The results of aircraft crash probability calculations are shown in Table 2.3- below.

Table 2.3-1 Probabilities of aircraft crash per type on the Cigeo surface facilities

Probability of aircraft crash (per year)	Surface facility process building	Exhaust air extraction shaft in operating zone	Ramp zone firefighting water tank	Shaft zone firefighting water tank
General aviation	8.5E-06	1E-07	2.5E-06	9E-08
Commercial aviation	6E-08	5E-09	3E-09	3E-09
Military aviation	1.5E-06	9E-08	5E-08	5E-08
Total 3 categories	**1E-05**	**2E-07**	**3E-07**	**1.5E-06**

Concerning the risk of a helicopter crash on the identified targets, the approach adopted takes into account:

- as a bounding value, a maximum overfly time for each of the targets of ten seconds for each flight;
- one flight per month (therefore 24 takeoffs and landings per year);
- a safety coefficient of 0.1 due to pilot responsiveness in steering the damaged helicopter to a risk-free zone.

The bounding probability of a crash per year is shown in Table 2.3- below.

Table 2.3-2 Bounding probability of aircraft crash per year involving a helicopter for each of the targets

Probability of crash (per hour of flight)	Overfly time (in h)	Number of flights per year per heliport	Safety coefficient	**Probability of aircraft crash per year**
3.27E-05	2.78E-03	2.4E+01	1.00E-01	**2E-07**

With regard to assessments:

- the probabilistic objectives of the RFS-I.1.a are met for commercial aviation for all targets, therefore no provision is required regarding this type of aviation;
- for general aviation, the probabilistic objectives are met for the shaft zone firefighting water tank. However, the probabilities obtained show that the risk cannot be ruled out for the surface facility process building, the exhaust air extraction shaft of the operating zone and the ramp zone firefighting water tank. Provisions are applied for these targets in relation to this type of aviation;
- for military aviation, the probabilities obtained show that the risk cannot be eliminated for the process building only. For this building provisions are therefore applied in relation to this type of aviation. For the other targets, therefore, no provision needs to be applied;
- given the probabilistic objectives of RFS-I.1.a, design must take into consideration a helicopter crash for all targets. Nevertheless, the design provisions regarding general aviation cover the potential consequences of a helicopter crash in terms of safety.

Design provisions are therefore made, including:

- the nuclear surface facility process building regarding a military aircraft crash;
- the exhaust air extraction shaft of the operating zone (VVE) regarding a general aviation aircraft crash;
- the firefighting water tank in the ramp zone regarding a general aviation aircraft crash;
- provisions in design are specified for the facility in the form of physical protective measures regarding hazards that may occur involving a commercial aircraft.

2.3.1.2 Provisions

Provisions for the surface nuclear facility process building are as follows:

- concrete external walls and slabs designed to withstand military aviation (Rafale);
- earth wall and cover installed (for physical protection of underground architecture of facilities);
- storage of transport containers, primary packages and disposal packages prohibited at the edge of the process building;
- an additional level (called "containment space") located above the "C5 Inspection" and "Container unloading" sectors;
- rooms located above the process rooms providing additional containment in the event of an aircraft crash;
- The prevention of installing EIPs on the upper slab and the external walls of the building.

Provisions for the exhaust air extraction shaft are as follows:

- concrete walls and slabs designed to withstand a Cessna and/or Learjet type aircraft crash (general aviation);
- mobile fans on the surface for "emergency" reconfiguration of ILW-LL disposal cell extraction ventilation and associated flows.

In the event of a military aircraft crashing onto the surface facility, the civil works are mechanically designed to prevent kerosene from flowing through any cracks caused by the impact and to rule out any tunnelling phenomena. In the detailed design phase, particular attention will be paid to the expansion joints in the process zone.

Concerning the fire safety water tanks in the ramp zone, the three tanks considered, each providing a functional redundancy, are separated by distance and not aligned, in order to guarantee the integrity of at least one tank in the event of an aircraft crash.

2.3.2 Risks associated with the industrial environment and communications channels

2.3.2.1 Source of risk

The identification and assessment of the risks associated with the industrial environment and with communication routes are performed in accordance with the recommendations of RFS I1.b.

The industrial facilities and communication routes that might present risks for the INB are:

- facilities close to the sites;
- fluid networks or power grids;
- communication routes such as roads, railways or waterways.

Given the description of activities in the vicinity of the site (see Volume II, Chapter 2.7) and the very low level of industrialisation of the region, the sources of danger presenting risks for the INB are limited:

- Environmentally regulated facilities (ICPEs):
  - ✓ the Syndièse platform (which is an environmentally regulated facility (ICPE) subject to declaration for the production of biofuel) is located northwest of Saudron some 2 km from the ramp zone and 4.5 km from the shaft zone;
  - ✓ the other ICPEs are located at a distance of more than 25 kilometres;
- Minor roads, located more than 500 m from the nuclear facilities:
  - ✓ D960 (connecting the communes of Saudron and Mandres-en-Barrois) currently crosses the ramp zone. It is planned to divert this road to the north of the site of the ramp zone;
  - ✓ D175, to the west of the ramp zone (connecting the communes of Saudron and Gillaumé).

The choice of site for the Syndièse project was implemented with knowledge of the potential site of the Cigeo project. The distance of 2 km is sufficient to eliminate any significant impact of an accident at Syndièse in relation to the Cigeo facilities.

2.3.2.2 Risk assessment and provisions applied

Concerning the communication routes, the main risks identified at this stage are associated with movement on the two roads mentioned above (minor roads D960 and D175) of tanker trucks that might carry flammable products (LPG, petrol, etc.). These roads are located close to Saudron, only the ramp zone facilities could be affected. The danger potential applied is a truck carrying 20 tonnes of GPL.

The two accident scenarios considered are:

- an accident involving a tanker truck containing LPG, potentially leading to a boiling liquid expanding vapour explosion (BLEVE) on the tanker truck;
- a leak on a tanker truck transporting LPG leading to the formation and ignition of a cloud of flammable gas (unconfined vapour cloud explosion or UVCE).

At this stage of design, the targets to be protected from the effects of such accidents are the outer walls of the buildings located on ramp zones and shaft zones, which include elements that are important for protection.

<u>Accident scenario with BLEVE on a tanker truck</u>

The quantification of the effects of the BLEVE was implemented with reference to the circular of 10 May 2010 (34) summarising the methodological rules applicable to hazard studies, assessment of the at-source risk reduction approach and technological risk prevention plans (PPRT) in the facilities classified in accordance with the Act of 30 July 2003 (35) and the Order of 29 September 2005 (24) concerning the assessment and consideration of the probability of occurrence, kinetics, intensity of effects and severity of consequences of potential accidents in studies of hazards for classified facilities subject to authorisation and it is presented in the tables below.

Table 2.3-3 Range of BLEVE thermal effects

Thermal flux	600 $(kW/m^2)^{4/3}.s$ 3 kW/m² (irreversible effects on people)	1,000 $(kW/m^2)^{4/3}.s$ 5 kW/m² (first lethal effects, first significant impacts on structures, threshold for destruction of windows)	1,800 $(kW/m^2)^{4/3}.s$ 8 kW/m² (significant lethal effects, appearance of severe damage to structures)
Range	**210 m**	**170 m**	**120 m**

Table 2.3-4 Range of BLEVE overpressure effects

Overpressure	300 mbar (Very severe damage to structures)	200 mbar (Threshold for domino effects) (Significant lethal effects on people)	140 mbar (Severe damage to structures) (First lethal effects on people)	50 mbar (Slight damage to structures) (Irreversible effects on people)	20 mbar (Threshold for significant destruction of windows)
Range	**35 m**	**45 m**	**65 m**	**130 m**	**260 m**

In relation to safety targets (mainly containment barriers) to be protected from this type of accident, the threshold of 5 kW/m² (or 1000 (kW/m²)4/3.s) corresponding to primary damage to structures and the threshold of 50 mbar corresponding to slight damage to structures are applied.

The assessed effect ranges are shorter than the distances of 500 m between the roads considered and the targets (Cigeo surface facilities).

<u>Scenario of leak from LGP tanker truck, leading to formation of a cloud of flammable gas, followed by burning (UVCE)</u>

The case of a leak from an LPG tanker truck, entailing formation of a cloud of flammable gas (propane, in most cases) then burning, has been considered.

The assumptions considered are as follows:

- 20 tonne LPG truck (tank volume: 47 m3 with filling rate of 85%);
- leak resulting from break in a branch connection (80 mm diameter);
- height of release considered at 1 m;
- pressure of propane equal to saturated steam pressure at temperature of 15°C (ambient temperature).

The quantification of the effects of the UVCE are shown in the tables below.

Table 2.3-5 Range of UVCE thermal effects

Thermal flux	600 $(kW/m^2)^{4/3}.s$ or 3 kW/m^2 (irreversible effects on people)	1,000 $(kW/m^2)^{4/3}.s$ or 5 kW/m^2 (first lethal effects, first significant impacts on structures, threshold for destruction of windows)
Range	**225 m**	**205 m**

The scenario of dispersion of the cloud and explosion was modelled using the Phast software (version 7.0); the results are shown in Table 2.3-.

Table 2.3-6 Range of UVCE overpressure effects

Weather conditions (wind speed and atmospheric stability)	Conditions 3F (night) 3 m/s Very stable	Conditions 5D (day) 6 m/s neutral
Maximum range at which the 20 mbar overpressure threshold (fragments of glass) could be exceeded (m)	**450 m**	**370 m**
Maximum range at which the 50 mbar overpressure threshold could be exceeded (m)	**300 m**	**240 m**

These effect ranges are shorter than the distances between the roads considered and the targets (Cigeo surface facilities). No overpressure effect can reach the facilities.

The results of the analysis of these road accident scenarios lead to the conclusion that there is no impact of road accidents on the Cigeo facilities. No special provision is applied.

2.3.3 Risks associated with earthquake

2.3.3.1 Presentation of risk

As well as the deterioration of buildings and structures, earthquakes can cause the degradation or loss of equipment that contributes to the performance of safety functions, either by direct destruction of this equipment or by hazards generated (creation of projectiles (debris), loss of electrical power supply, load drop, loss of cooling, fire, etc.).

An earthquake is therefore likely to lead to:

- breaking of containment barriers, which can lead to the dispersion of radioactive materials;
- breach of radiation protection that could lead to exposure of personnel or of the environment;
- failure to maintain subcritical conditions, in particular the deformation of equipment that has safety based on its geometry;
- inadequate removal of heat from rooms holding highly exothermic sources (buffer zone for CPs, CSs and casks, transport containers);
- inadequate removal of radiolysis gases in the rooms holding ILW-LL CPs or CSs that could lead to an explosion.

2.3.3.2 Method for defining design requirements

Taking account of an earthquake entails defining earthquake design requirements for certain components of the facilities to minimise the environmental impact.

The design calculations for the equipment and systems of the facilities take account a Safe Shutdown Earthquake (SMS) defined as the extreme conventional seismic load specific to the site (see Section2.3.5 of Volume II), or even the Maximum Physically Possible Earthquake (SMPP) for the facilities contributing to safety after closure (see Section2.3.5 of Volume II).

Seismic design is therefore required for components whose failure in the event of an SMS could have a significant impact on personnel and on the environment. These are components:

- where failure or dropping could lead to unacceptable consequences for safety (loss of safety functions (FS));
- which, if they are damaged or dropped, could cause degradation of equipment that contributes to a Safety Function (FS).

In accordance with the function to be performed after an earthquake, the design criteria to withstand an SMS for these components concerns:

- leaktightness;
- component strength;
- component operation.

These criteria lead to requirements to be applied for the components concerning performance under earthquake conditions:

- stability: the component must not become a projectile that could harm targets whose integrity and/or functional strength during and/or after earthquake are required.
- integrity: the component must maintain a passive function:
  - ✓ conservation of location;
  - ✓ conservation of geometry;
  - ✓ conservation of watertightness;
  - ✓ conservation of fire resistance level;
  - ✓ Securing the load handled.

Functional performance: the component must maintain active function:

- ✓ after earthquake;
- ✓ during and after earthquake.

The stability and integrity of a component require correct design of support fittings and anchors and compliance with allowable stresses on its structure.

Guaranteeing the functional performance of a component consists in ensuring correct performance or availability when subjected to extreme vibrations generated by the earthquake. This depends on the level of requirement to be met after the earthquake (for example, whether or not the process must be restarted).

The components contributing to safety functions, with functionality required during and after earthquake, are qualified systematically for earthquake. The qualification provides proof of the resistance of the equipment under identified or standard conditions.

In the special case of civil works elements, the safety requirements take the form of the following seismic criteria:

- the structure concerned provides a support and protection function for a component sized for an SMS. It must remain stable under earthquake.
- the structure does not create interactions likely to threaten the integrity of structures that must remain stable under an earthquake (e.g. a building located close to a building dimensioned to withstand an SMS).

2.3.3.3 Provisions applied

Conceivable provisions in terms of safety functions are as follows:

- for risks associated with the dispersion of radioactive materials:
  - ✓ SMS design for rooms and docking facades/walls (including during docking of casks and transport containers) ensuring a containment function;
  - ✓ SMS design for the structure supporting the ILW-LL transfer casks;
  - ✓ maintaining a level of extraction in the event of an SMS affecting nuclear ventilation;
  - ✓ SMS design for devices used to monitor atmospheric contamination in certain rooms and outlet releases to ensure correct performance after an earthquake.
- for external exposure risks:
  - ✓ SMS design for equipment that fulfils a radiological protection function (walls, port holes, docking facades, penetrations, doors, etc.);
- for risks associated with the release of radiolysis gases:
  - ✓ maintaining a certain level of extraction in the event of an SMS in the ILW-LL zone and restoring extraction within a time period compatible with the time it will take for an explosive atmosphere to form;
  - ✓ SMS design for systems used to restore hydrogen concentration monitoring in the ILW-LL disposal cell after an earthquake;
  - ✓ SMS design for processes and civil works to allow time for an operation after earthquake that is compatible with the time it will take for an explosive atmosphere to form (possibility of removing cask or flushing the atmosphere).

Provisions regarding safety functions are as follows:

- for risks associated with loss of power supply:
  - ✓ SMS design for electrical power supply networks that must ensure post-earthquake operation (electrical cables, electrical equipment, such as cable trays, cabinets, electronics racks, etc.);
  - ✓ SMS design for the power supply unit backed up via generators;
- For risks associated with the loss of monitoring:
  - ✓ SMS design for certain equipment used for monitoring protective functions in the facilities;
- For risks associated with the loss of instrumentation and control:
  - ✓ dimensioning to withstand an SMS for instrumentation and control of equipment that must be kept in operation during and/or after an earthquake.

The provisions applied in terms of protective functions for protection against hazards are as follows:

- for risks associated with a fire:
  - ✓ SMS design for fire detection systems to ensure their operation during and after an earthquake;
  - ✓ SMS design for the stationary firefighting systems in the process cells and handling cells to ensure their operation during and after an earthquake;
  - ✓ SMS design for fire dampers in rooms with radiological inventory to allow their closure after an earthquake;
  - ✓ SMS design for walls, doors and penetrations used for fire compartmentation (fire compartment, evacuation route, or emergency access route), with doors operational after an earthquake;
  - ✓ SMS design for ventilation systems (fans, ducts, filters) used to extract smoke from fire compartments, containment sectors and compartmentalised zones;

- for flooding risks:
  - ✓ SMS design for the surface facility firefighting water network, the firefighting water network in surface-bottom connections and the underground facility, and the fire-extinguisher water collection networks;
  - ✓ SMS design for tanks and containers associated with potentially contaminated effluent collection networks;
  - ✓ SMS design for the network and containers for water seepage collection in the underground operating zone;
- for risks associated with waste package acceptance, conditioning, transfer, docking and disposal:
  - ✓ SMS design for equipment likely to become projectiles and damage safety targets;
  - ✓ SMS design for shunters, bridge cranes, gantries, lift tables, turntables and docking facades, remote manipulators, limited lift machines (MLL), transfer carts, shuttles, pusher and puller robots, ramp transfer system device to secure the handled or transferred load (waste package, cask);
  - ✓ SMS design for running tracks to maintain correct geometry;
  - ✓ SMS design to guarantee operation after an earthquake:
    - CP/CS transfer equipment (cart, shuttle, ramp transfer system, etc.);
    - stacking carts and cranes, lift table and transfer table located at the ILW-LL disposal cells;
- For risks associated with co-activity:
  - ✓ SMS design for separation airlocks between construction zone and operating zone.

The other constructive provisions are as follows:

- for civil works elements:
  - ✓ SMS design for at least EP1 buildings, ramp heads and shaft heads in the operating zone, ramps, shafts and operating ZSL, connecting drifts, access drifts, air return drifts and cross cuts, as well as disposal cells;
  - ✓ MPPE design for underground structures (including surface-bottom connections) providing protection functions for the post-closing phase;
- for stacks of waste packages:
  - ✓ waste packages designed to remain stable during an SMS when stacked (no waste packages falling, functions not impaired by impacts between packages, restricted movement of packages);
  - ✓ waste package stack and disposal cells designed to prevent the movement of waste package stacks in an earthquake (SMS) from damaging the radiation protection walls in the handling cell.

In view of the provisions made, a safe shutdown earthquake (SMS) should have no impact on facility safety. An on-site emergency plan (PUI) design situation consisting in checking facility robustness with regard to an earthquake level slightly higher than the SMS has been identified and will be studied in the detailed design phase (APD).

2.3.4 External flooding risk

2.3.4.1 Risk description

The risks of external flooding for the nuclear surface facilities are associated with the presence of water (rain, spillage, storms, break in external pipes, etc.) around the INB. The presence of this water and the hazards for nuclear facilities are that it can lead to risks of dispersion of radioactive materials in the facility and in the environment (water as transfer vector), risks of loss of electrical power supply, loss of fluids and utilities (flooding of equipment), risks of fire produced by occurrence of a short circuit following splashing or spilling of water onto electrical equipment.

The risks of external flooding for the underground facility are associated with water coming into the ramps and shafts from the surface facilities, seepage from the subsoil that is not expected or that exceeds theoretical design values in the surface-bottom connections, in particular when entering the main aquifers, as well as seepage in underground drifts.

Taking these risks into account in facility design ensures the control of risks generated by weather conditions such as heavy rain, runoff from water catchment areas, rising water table and overflowing rivers. the risk of flooding may also be induced by the presence of basins, pipes or reservoirs close to nuclear facilities, where a failure or hazard could lead to the release of large quantities of water and threaten important facility structures or equipment.

2.3.4.2 Safety requirements

The components and fixtures that perform safety functions in the Cigeo surface facilities are designed to withstand flooding of external origin in accordance with the approach and recommendations presented in ASN Guide no.13 concerning the protection of basic nuclear installations against external flooding.

2.3.4.3 Surface facilities

Reference situations for flooding risk

In accordance with the ASN guide, the reference situations to be taken into account to analyse the flooding risk (reference flood situation of RFS) for the Cigeo site are as follows:

- "Local rain" SRI,
- "Flooding on small river basin" SRI
- "Rising water table" SRI
- "Degradation or malfunctions of structures, circuits or equipment" SRI,
- "Swell" SRI,
- "Local rain" SRI

Management of effluents (including rainwater) in the surface facilities is described in Volume II.

In accordance with the requirements of the ASN guide, the definition of the contingency level for the reference rain is defined by the upper boundary of the confidence interval at 95% of the hundred-year rainfall calculated using data from a weather station that is representative of the site conditions.

The main provisions applied in relation to the "local rain" SRI are as follows:

- the rainwater removal systems are dimensioned in order to prevent saturation of systems that could lead to ingress of water into the buildings containing key equipment for protection. In addition, the facility must deal with a surface runoff scenario, taking into account unavailability of access points to the local rainwater drainage system. The rainwater drainage systems will be subject to regular monitoring in order to ensure that there are no obstructions present;
- the rainwater drainage devices for water coming from the roof(s) route the water to the outside of the buildings;
- the openings of rooms on the periphery of the nuclear surface facilities that open onto the outside are protected against incoming water and against bad weather. The access points to the buildings also have trenches and thresholds to prevent water ingress into the facilities.

"Flooding on small river basin" flood risk scenario

The hydrographic system around the Cigeo site (ramp zone and shaft zones) is included in Volume II.

The main zone concerned for the risk of flooding in Meuse is the Ornain valley between Abainville and Menaucourt. In addition, observations have shown flooded zones corresponding to a part of the Ormançon valley upstream of Mandres-en-Barrois, a large part of the Orge valley and a part of the Saulx valley, upstream of Ecurey.

The elevation of the nearest waterway (the Orge) to the ramp zone of the surface facilities is about 325 m above sea level for a location of the platform of the building EP1 at 358 m above sea level (top side of invert). Concerning the shaft zone, the elevation of the nearest waterway (the Ormançon) is about 330 m above sea level with emerging structures at 365 m above sea level.

The altitude of the location of the facilities both on the ramps side and on the shaft side makes it possible to eliminate the risk of external flooding due to flooding of the waterways located nearby.

"Rising water table" flood risk scenario

This paragraph deals with the risk of the rising water table at building EP1 of the surface facilities. The risk of flooding at the ramps and shafts is covered in the flood risk scenario of "infiltrations coming from aquifers" for the underground facility (Section 2.3.4.4)

Water level measuring points are available close to the ramp zone and the shaft zone. The available data is taken from the drill holes implemented between 1996 and 2010. For all the structures, to varying degrees, a clear correlation is observed between the piezometric fluctuations recorded and the rainfall. These fluctuations can range from a few tenths of metres to several metres. The reaction to an intense rainfall event takes place less than 24 h after the start of the rain, and once the rain has passed the piezometric level returns more or less rapidly to a level close to its starting level. In the water table, such "karstic" reactions represent a high permeability of karstic conduits, a relatively low porosity of the matrix and an absence of storage of seepage water.

At this stage of the studies, the analysis of the piezometric data has been used to define a frequent water level (level likely to be exceeded 1% of the time) around the facilities of the ramp zone at about 359 m above sea level. In addition, an initial analysis based on the recommendations of the ASN guide made it possible to define a reference flood risk scenario of about 363 m above sea level (level associated with a hundred-year return period applying the upper boundary of the confidence interval of 95%). All of these values will be subject to additional assessments in the construction licence application.

At the APS stage, regarding the need to have a facility built underground as a physical protection measure (see section 2.3.1.1), the upper surface of the foundation invert of the level + 0 m of building EP1 is located at 358 m above sea level. Consequently a sealing/drainage system under the foundations and against the outer walls has been defined in order to control the risk of external flooding arising from a rising water table. This system is used to collect and monitor water before release into the natural environment. It will be designed to operate throughout the lifetime of the facility and to facilitate inspection and maintenance. It should be noted that other technical solutions are still under study and changes may occur at construction licence application stage.

"Degradation or malfunctions of structures, circuits or equipment" flood risk scenario,

the risk of external flooding may come from openings, circuits and equipment installed outside of or on the site, outside the buildings receiving EIPs.

At this stage of design, the elements identified as requiring analysis in terms of this risk are the following:

- the water supply networks distributed by the site and the associated tanks (drinking water, washing water and recycled water, hot heating water and chilled water, firefighting water);
- rainwater collection basins;
- firefighting water reserves.

The elevation of tanks associated with water networks (drinking water, recycled water), rainwater collection basins and firefighting water reserves ensure that a failure is not likely to present a hazard to nuclear facilities located at a higher level.

Given the associated lesser challenges, the analysis of the risk of external flooding due to a break in a water supply network will be conducted as part of the construction licence application. The objective of the analysis, in accordance with the approach specified in the ASN guide, will be to ensure that the design provisions made can guarantee that a single or multiple break in these networks outside a buildings containing EIPs does not lead to water coming into these buildings.

"Swell" flood risk scenario

Swell is a wave resulting from a rapid variation in flow rate in a hydraulic structure open to the atmosphere, located on the site or upstream or downstream of it. It is characterised by its intensity (maximum flow rate, corresponding maximum water height on-site, volume flowing) and duration (taking account of the various dynamics associated with the main wave and the effects accompanying this main wave).

The balancing tanks installed on the rainwater collection and removal network are located at levels far lower than the installation platforms of the nuclear surface facilities. At this stage of design, the elevation is about 10 m between the tanks and the EP1 platform on the ramp side or the emerging structures on the shaft side). Given the elevations involved, any swell in the tanks would be unlikely to lead to a risk of external flooding.

2.3.4.4 Underground facility

The risk of water seepage from the aquifers crossed by the surface-bottom connections, ramps (including ramp head) and shafts, is to be taken into account. The description of the hydrogeological system around the site is provided in Section 2.4 of Volume II of this document.

For the design of the ramps, provision is made at this stage for a leaktight liner of Barrois limestone and draining outside the Barrois, as well as a designing draining cross cuts between ramps in the Kimmeridgian and Oxfordian. The system draining the outer surface of the liner segments (gravel) includes regular openings/flows to gather the drained water in internal side manifolds. These draining provisions are applied as far as the COX roof. At the penetration of the aquifers, a peripheral seal is implemented with the aim of limiting water ingress and preventing communication between aquifers. Trenches for recovery of drainage water in the two ramps are used for gravity evacuation of this water into two tanks positioned in a cross cut at the foot of the ramps. These two tanks are connected to each other at the top, in order to ensure that the overflow is operating correctly. The water contained in these tanks is sent continuously to the surface for analysis and treatment by the drainage water network.

For design of the shaft, it is specified at this stage:

- a leaktight liner over the entire height of the VVE shaft,
- a leaktight liner in the Barrois aquifer and a liner designed to withstand hydrostatic pressure with no need for drainage systems in the other cover formations. Systems for recovery of seepage water at the foot of the shaft collect the water and take it to the surface for analysis and treatment by the drainage water network.

The theoretical hydraulic pressures to be applied to the sealed design structures, based on each of the formations.

In the underground facility, in the COX, the outer surface of the liner segments is filled with concrete and considering the extremely low flowing speed of the water it can be stated that the water in liquid state will not penetrate inside the structures in the short and medium term.

There may be seepage of water into HLW cells (unventilated) during filling phases. The cells are designed with a 2% slope towards the cell entrance. The water that may enter there is taken up by a collection network located at the entrance of the cells and buffer tanks located at the lowest point in the sections.

2.3.5 Risks associated with extreme weather or climate conditions

2.3.5.1 Presentation of risks

The extreme climate conditions taken into account in the analysis of risks are:

- heavy rain that could cause external flooding of the facility. This risk is analysed in the chapter concerning the risk of external flooding;
- extreme temperatures (maximum and minimum) causing difficulties to maintain acceptable temperatures within the INB and a risk of a malfunction of certain systems and equipment;
- high winds that could turn into a tornado and are likely to trigger a malfunction of certain systems and equipment (ventilation and monitoring systems), and damage to structures;
- heavy snowfall that could cause damage to structures and equipment.

2.3.5.2 Extreme temperatures

The extreme outside air temperatures taken into account in facility design are described in Volume II Section 2.5.1.1 and summarised in Table 2.3-. The temperatures applied cover conceivable rises in temperature as a result of climate change.

Table 2.3-7 Extreme temperatures considered in Cigeo design

Long-duration minimum/maximum temperature (for at least 7 days) with a return period of fifty years (Θ7d). It represents the temperature conditions that can occur frequently and can be considered relevant for normal continuous operating conditions, throughout the operational period. The normal operating temperature range applied covers the temperatures likely to occur according to the various conceivable climates and the scenarios established as part of global warming.	-15°C/+35°C Based on the summary of meteorological data from the site from 2003 to 2011 and scenario CR according to the Köppen classification.
short duration minimum/maximum temperature (24 hours) with a return period of 100 years (Θ24h). It is representative of a temperature only occurring for limited periods of time and at limited frequencies. For design purposes, this temperature can be increased depending on the particular issues concerned (sensitivity of facilities, climate change over the operating period) and is considered for a period of 7 days.	-20°C/+40°C Based on the summary of meteorological data from the site from 2003 to 2011.
Instantaneous minimum/maximum temperature calculated using hundred-year values (Θ6h). For design calculations, this temperature is defined by application of a fixed value of +/- 5°C in relation to Θ24h. The values obtained are higher than the extreme temperatures recorded at St Dizier and Epinal.	-25°C/+45°C Applying a fixed value of +/- 5°C for Θ24h.

The main risk associated with extreme temperatures for Cigeo is a risk of malfunction of the ventilation of the surface and underground facilities following a failure of the electrical power supply, ventilation equipment or monitoring equipment, which might be caused, in particular, by hot air coming in, in the event of a period of extreme heat or ice on the air intakes in the event of extreme cold. A malfunction of the ventilation is likely to cause difficulties as follows:

- difficulty in maintaining acceptable temperatures within the facilities, in particular compromising heat removal function for heat released by the waste packages;
- difficulty in removing the radiolysis gases produced by the waste packages.

The Cigeo facilities, however, are not very sensitive to extreme temperatures (no cooling function and high thermal inertia).

Nevertheless, in terms of these risks, the following provisions are applied:

- ventilation design for the surface facilities at Θ 7d;
- installation of an anti-ice device on the fresh air intake;
- design of various equipment associated with the operation of the exhaust air extraction of the underground facility at Θ24h and Θ6h to remove the thermal power of HLW disposal packages in the underground facility and radiolysis gases in ILW-LL disposal cells;
- monitoring external and internal temperature for certain rooms with the possibility of adjusting the air supply temperature;
- the possibility, if necessary, of issuing a Meteo France alert to take facility safety measures (temporary interruption of ventilation, for example).

2.3.5.3 High winds and tornadoes

The main risks associated with strong winds and tornadoes at Cigeo are:

- a mechanical overload produced by the wind likely to cause damage to equipment or infrastructure, in particular, the train unloading area and the exit of the underground facility ventilation shafts;
- major variations in pressure likely to cause a malfunction of the ventilation for the surface and underground facilities (disruptions to air flow, even destruction of equipment);
- movement of objects ("projectiles") likely to cause damage to equipment or infrastructure.

These risks can impact the protection functions of "removal of heat from waste packages", "removal of radiolysis gases" and "containment".

The usual provisions are made regarding these risks, namely:

- facility design:
  - ✓ nuclear surface facilities, connecting drifts, the head of the waste package ramp, conventional surface facilities containing EIPs and shaft heads are designed for tornado of level EF3 on the Fujita scale (wind speeds between 219 and 266 km/h), including in particular:
    - container preparation and docking halls;
    - corridors and cells shielded from the nuclear process, containing primary packages and disposal packages;
    - connecting drifts and the head of the waste package ramp;
    - dedicated shaft heads for fresh air provision and exhaust air return for underground facility;
  - ✓ the loading/unloading bay for rail and road convoys is dimensioned for an EF2 category tornado on the Fujita scale (i.e. wind speeds between 179 and 218 km/h). In this bay, the waste packages are placed in robust transport containers providing them with the mechanical strength required to withstand the collapse of light structures or flying debris;
- redundancy and geographical separation of the underground facility ventilation system air supply and extraction fans, and the generator units;

- nuclear ventilation for surface and underground facilities is designed take into account head loss due to extreme winds;
- orientation of air intakes and release outlets depending on the direction of the dominant winds on the site;
- installation of anemometers;
- the possibility, if necessary, of issuing a Meteo France alert to take facility safety measures (temporary interruption of ventilation, for example).

2.3.5.4 Snowfalls

The main risks associated with snow for the Cigeo facilities are:

- the mechanical loads generated by the weight of the snow on the infrastructure or equipment likely to cause damage to it, or even lead to collapse;
- blocking facility ventilation air intakes.

They are likely to compromise the protection functions of "removal of heat from waste packages", "removal of radiolysis gases" and "containment".

The characteristics of the snow zone in which the Cigeo facilities are located are as follows:

- normal snow load: 35 daN/m²;
- extreme snow load: 60 daN/m².

In terms of these risks, the provisions applied are those conventionally put into place, i.e. the following:

- design of surface facilities (including the train loading/unloading bay), connecting drifts, head of waste package ramp, conventional facilities containing EIPs, and dedicated shaft exits for fresh air intake and exhaust air return of the underground facility for a load of 60 daN/m²;
- the possibility, if necessary, of issuing a Meteo France alert to take facility safety measures (temporary interruption of ventilation, for example);
- a snow removal procedure (shafts, roofs).

2.3.6 Risks associated with lightning and electromagnetic interference

2.3.6.1 Lightning

Lightning, with its direct effects, may be a source of damage (fire, damage, even destruction) to the structures providing safety functions or to equipment necessary for achieving and maintaining a safe state for the facilities. Through its indirect effects, lightning can be a source of overvoltages of atmospheric origin, possibly causing damage to equipment important for protection that makes use of electronic, computer or electrotechnical equipment. The lightning risk concerns the surface facilities as well as the underground facility

The approach defined in the Order of 15 January 2008 on lightning protection (36) for environmentally regulated facilities (ICPE) is adopted to address the lightning risk for Cigeo nuclear facilities.

In accordance with the associated regulations, an analysis of the lightning risk will be performed as part of the construction licence application in accordance with standard NF EN 62305 on lightning protection (36). This analysis will allow for identification of the equipment and facilities that must be protected and will define an associated level of protection. Depending on the results of the analysis of the risk of lightning, a technical study will be performed in order to precisely define the preventive measures and the protective devices, the location for their installation and the details of their checks and maintenance. The analysis of risks associated with lightning and the associated technical study were conducted by competent organisations.

At this stage of design, the main provisions applied in relation to the lightning risk are the following:

- lightning capture devices (rods with mesh and down conductors);
- earth connection network (including the steel reinforcements in the walls connected to the earth connection network);
- limitation of surge currents and overvoltages on the distribution network by implementation of lightning rods.

2.3.6.2 Electromagnetic interference

Electromagnetic interference (EMI) is a signal or an emission, travelling through the air or via electrical conductors or signals that can harm the operation of a system, in particular a safety system. As an example, potential consequences for safety at Cigeo are erroneous signals that could lead to the untimely startup or shutdown of handling equipment, losses of monitoring sensors (releases, flow rate, negative pressure, etc.).

In order to prevent these risks, the facility is designed in accordance with the standard IEC 61000, which sets out the general principles to be followed to protect facilities against electromagnetic interference. This standard will be applied to the whole facility.

At this stage of design, the main provisions applied in relation to the risks associated with electromagnetic interference are the following:

- earth network and electrical protection of power supply lines and electrical equipment;
- earthing of shielded cables and electrical and inert mechanical equipment;
- limitation of couplings by separation of high power and low power cableways, and by use of metal cableways connected to earth;
- installation of filters on the electrical connections in interface with a switchboard, control unit or sensitive equipment;
- protection of sensitive equipment using surge protectors, ferrites and transformers.

2.3.7 Risks associated with an external fire

2.3.7.1 Source of risk

The natural and industrial environment of the site must be taken into account in relation to the consequences of an external fire close to the INB.

The natural environment consists of forest and green space. A fire risk might occur in the ramp zone and in the shaft zone.

The industrial environment includes:

- the fixed installations for fuel or fuel oil reserves;
- vehicles of personnel or those required for operation;
- the worksite installations in the construction zone, in particular the hazardous products storage zones and worksite waste storage zones (skips or containers).

2.3.7.2 Preventive measures

The preventive measures are mainly based on measures aiming to control occurrence of a fire close to the facilities located at the surface in the shaft zone and the ramp zone, by limiting the hazard sources nearby.

For the natural environment, given the type of vegetation at the INB location and the climate of the Alsace Lorraine Champagne Ardenne region, the risk of forest fire is not identified as a major risk according to the natural risk prevention plan (PPRN). In addition, trees and undergrowth shall be cleared around the INB at the time of construction and green spaces will be maintained during operation.

Regarding the risk of an outbreak of fire due to natural causes, the following conditions shall be met around the INB:

- clear distance of at least 50 metres around the buildings (trees and undergrowth cleared);
- cleared distance of at least 80 metres on either side of the surface nuclear facility fence.

The vegetation on the EP1 semi-underground facility is designed not to affect the exits in the event of a vegetation fire.

For the industrial environment, in order to prevent the start of a fire involving a fuel or fuel oil tank, it is prohibited to store a flammable product close to the INB. More generally, in order to prevent any impact of an external fire on the INB, a minimum distance is defined concerning the physical and chemical properties of the equipment and products present as well as the containers concerned. Table 2.3- shows the distances of surface buildings from the INB.

Table 2.3-8 Distances of buildings from the INB

Ramp zone	**Distance from INB**
Utilities production building	50 m
Conventional waste sorting building	>100 m
Electrical substation (90 kV)	30 m
Transformer substation (90 à 20 kV)	30 m
Fuel Service Station	35 m
Shaft zone	**Distance from INB**
Utilities production building	> 40 m
Conventional waste sorting building	> 40 m
Electrical substation (90 kV)	> 40 m
Transformer substation (90 à 20 kV)	> 80 m
Fuel Service Station	> 100 m

In addition, parking is controlled and the car park zones are marked in order to mark off the authorised parking zones. At the outskirts of the INB, technical provisions for parking are installed in order to prevent parking at less than 10 metres from the nuclear buildings.

Finally the location of any other building close to the INB surface facilities is sufficiently distant to avoid a domino effect and propagation of a fire starting within these buildings.

2.3.7.3 Mitigation measures

The equipment and organisational structure set up within the INB for control of the fire risks, particularly internally, will allow for effective interventions to counter this risk.

2.4 Combinations of hazards

A combination[61] of two hazards is applied where a dependence is known or presumed between the two events or when a risk of concomitance is identified in view of the duration and frequency of one or other of the events.

The initiating events (hazards or failures) likely to lead to the most severe consequences are identified in the analyses dedicated to each type of risk. The analysis of combinations consists in identifying:

- whether the occurrence of a combination of an additional risk in relation to an already identified initiating event can lead to an aggravation of the potential consequences of this event;
- if two undesirable events already identified could be combined and therefore lead to an aggravation of the potential consequences of each of these two events.

The table below shows the plausible combinations of hazards considered.

[61] This section is not concerned with the induced effects.

Table 2.4-1 Plausible combinations of hazards (including domino effect scenarios)

	Hazards with low probability of occurrence and/or with potential momentary effects									**Hazards with high probability of occurrence and/or with potential lasting effects**			
Initial hazard / **Accumulated hazards**	Projectiles and ESP	Aircraft crash	Fire	Explosion	internal flooding	Lightning and EMI	Indus. com routes	Hazardous materials	Earthquake	Extreme weather	External flooding	Loss of electrical power supply	Loss of utilities
Flying projectiles and ESP		✓	✓	✓		✓			✓	✓ / X	✓		
Collisions and falling loads	✓		✓	✓		✓			✓	X	[62]	✓	
Fire	✓		[63]	✓		✓	✓		✓	✓ / X	X	X	X
Explosion	✓	✓	✓			✓	✓	✓	✓	✓ / X	X	X	X
internal flooding	✓	✓	✓	✓					✓	✓ / X	✓ / X	X	X
Lightning and EMI										✓	✓		
Activities and communication channels										X	X		
Emissions of hazardous substances	✓	✓	✓	✓	✓		✓		✓	✓ / X	✓ / X		
Earthquake										X	X		
Extreme weather conditions											X	X	X
External flooding									ECS	X		X	X
Loss of electrical power supply	✓	✓	✓	✓	✓	✓	✓		✓	✓ / X	✓ / X		X
Loss of fluid supply and utilities	✓	✓	✓	✓	✓	✓	✓		✓	✓ / X	✓ / X	✓ / X	

Key:

- plausible dependent combinations (domino effects): ✓
- plausible concomitant combinations: X

At this stage of studies, the safety options associated with the combination of hazards are mainly focused on the design of the facility and its equipment regarding the following types of external hazard: earthquake, external fire, aircraft crash, climate conditions likely to generate an incident/accident in the facility, such as internal fire, loss of utilities, failure of handling equipment.

[62] : In the event of occurrence of external flooding that could harm the facilities, it is postulated that operation is interrupted for this period, and that therefore the risk of collision and of load-drop is not to be combined.

[63] : Given the scale of the Cigeo site, an additional scenario aimed at considering the simultaneous and independent occurrence of two fires breaking out at the facilities may be taken into account. Effects could include emergency resources being unavailable within the required time, with the result that a fire would be likely to last longer than is currently allowed for in the design of rooms for which the safety demonstration involves emergency response operations.

The plausible concomitant hazard combinations identified at this stage, which will be subject to further studies, are as follows:

- combination of aircraft crash or collision during an extreme climate episode;
- combination of a fire with external flooding;
- combination of a fire with an aircraft crash or collision;
- combination of a fire with a loss of electrical power supply;
- combination of a hazard of the industrial activities and communication routes type during a period of extreme weather;
- combination of a hazard of the industrial activities and communication routes type during external flooding;
- combination of an earthquake with a fire;
- combination of an earthquake with loss of electrical power supply;
- combination of an external flood with an extreme climate episode;
- combination of loss of electrical power supply with an extreme climate episode.

2.5 Risks associated with co-activity

2.5.1 Source of risk

The risks associated with co-activity result from simultaneous or successive performance of operations in the same geographical zone or requiring the same utilities or services. The various operations and interferences between these operations are likely to transfer potential hazards from one zone to another, or from one activity to another.

2.5.1.1 Co-activity situations

The co-activity can be "direct", where several activities interfere directly with each other, or "indirect", where the interaction between the various activities takes place via a shared interface, for example use of the same utilities or service.

There are several different modes of co-activity:

"Sequenced" co-activity, i.e. sequencing of activities with a predecessor/successor link;

- "Geographical" co-activity, i.e. simultaneous activities that take place near to each other;
- "Equipment" co-activity, i.e. simultaneous activities sharing equipment;
- "Functional" co-activity, characterised by use of functions shared by several activities.

The specific characteristics of the Cigeo project are:

- gradual deployment of facilities in terms of space and over time: the disposal structures will be built gradually as the disposal facility comes into operation. Structures are therefore brought into operation as part of an intermittent and gradual process;
- a main activity of the operating facility that consists of handling operations and internal transfers of waste packages containing radioactive materials. Peripheral or periodic activities of the facility, such as support, maintenance or monitoring activities, must therefore coexist continuously with "mobile hazard" sources, namely transport containers at the surface and disposal packages in transfer containers underground;
- dismantling and closing of facilities in stages.

Four types of co-activity specific to the Cigeo project are studied as from the beginning of design. These are:

- simultaneous performance of nuclear processing activities and construction of structures, in particular in the underground facility, i.e. Operation/Construction co-activity, including in connection with sequencing of activities in a given zone, i.e.:
  - ✓ excavation and construction of new disposal cells, tunnels and sections;
  - ✓ changeover/transfer of new disposal cells, tunnels, and sections from the "Construction Zone" to the "Operating Zone", after installation of equipment, performance of tests and authorisation of changeover/transfer issued after checking the correct performance of the technical process described in Section 2.5.2.1,
  - ✓ operation of these sections;
- carrying out simultaneous nuclear processing activities and maintenance operations, i.e. Operation/Maintenance co-activity;
- carrying out simultaneous nuclear processing activities and heavy maintenance and repair operations, i.e. Operation/Renovation co-activity;
- carrying out simultaneous nuclear processing activities and closure of disposal cells and tunnels, i.e. Operation/Closure co-activity (see Volume IV).

Certain types of co-activity, such as health and safety coordination within a single zone, or deployment and closure of the surface conventional and nuclear facilities are not presented at this stage of the project. Standard provisions are applied, such as setting up of prevention plans linking with health and safety coordination and performance of operations for construction, renovation and deconstruction of buildings at the surface, performed in independent closed worksites.

At this stage, given the challenges, the analysis is focused on the underground facility.

The main co-activity situations identified in the underground structures are summarised in the Table 2.5- below.

Table 2.5-1 Co-activity situation specific to the underground facility

Main co-activity situations	Co-activity modes
Coexistence in the underground facility of a construction zone (ZT) and an operating zone (ZEXP)	Due to sequencing based on physical location, equipment or function.
Transition of newly excavated sections from ZT to ZEXP	Due to sequencing based on physical location, equipment or function.
Co-activity between support activities (maintenance, monitoring, etc.) and the main activity (transfer of casks) in ZEXP	Material, geographical.
Co-activity between the activities of renovation and underground operation (transfer of casks)	Due to sequencing based on physical location, equipment or function.

2.5.1.2 Identification of risks associated with co-activity

Two major categories of potential risks are identified:

- risks resulting from the activities of excavation, equipping and support from a construction zone to an operating zone, and mainly:

  - ✓ fire, due to operations carried out with hot spots on sites and to the presence of vehicles (with fuel and tyres), which may spread and threaten the separations of zones located nearby;
  - ✓ projectiles following an explosion associated with the presence of ATEX zones (storage of flammable liquids, presence of pressurised cylinders, battery charging rooms);
  - ✓ flooding, in particular following a failure of an installation, infrastructure, activity, utility specific to worksites (industrial water, drinking water, firefighting water, etc.);
  - ✓ falling equipment or collisions of worksite vehicles that may degrade the performance of the separations present between the various zones;
  - ✓ losses of utilities, ventilation or systems for detection and monitoring during installations, tests or commissioning of new equipment (ZT/ZEXP transition zone);
- risks specific to operating activities concomitant with other peripheral support activities to the main process of waste package handling (maintenance, renovation). The main risks concern the containment of radioactive materials and radiation protection of workers, including:
  - ✓ risks of dissemination of radioactive materials to the construction zone following an accident in the nuclear zone (fire, collision);
  - ✓ risks of external exposure of personnel in the construction zone following an accident in the nuclear zone (fire, collision, etc.) or a degradation of radiation protection close to the construction zone;
  - ✓ risks of collision or blocking the nuclear process associated with crossed flows in the ZSL and in the connecting drifts during maintenance operations or renovation phases;
  - ✓ falling equipment and collision of vehicles used for tasks in the operating zone that might affect the static or dynamic containment of the zone in operation, the radiation protection and other safety elements (doors, fire compartments, fire dampers, etc.) located at the interfaces with the construction zone;
  - ✓ the SOHF risks generated by movement of equipment and people close to the interfaces between the zones, in particular in coordination with the necessary tests during the changeover from a construction zone to an operating zone.

The main risks located at the interfaces between the operating zone and the construction zone in the underground facility are presented in Table 2.5- below.

Table 2.5-2 Risks specific to the ZEXP/ZT interface

Description of main risks associated with the interfaces	Principal hazards
Impacts and collisions of worksite vehicles and equipment present on ZT side (projectiles, impacts) that could degrade the performances of the elements separating the two zones	Collisions/projectiles
Fire on vehicles or wheel-mounted equipment containing fuel in the ZT potentially able to damage the performances of the elements separating the two zones	Fire
Flooding in ZT, particularly in the event of a break in piping or in association with the presence of water seepage	Flooding
Presence of pressurised cylinders in the maintenance and storage zones of the operating and construction ZSLs	Explosion
Movement of transfer cask loaded with a waste package in the ZEXP close to the ZT	Risk of external exposure
Loss of containment barriers in accident conditions (cask, disposal package, ILW-LL disposal cell) in the ZEXP close to the ZT	Risks of dispersion of radioactive materials and of external and internal exposure
Changeover from a construction zone to an operating zone	Loss of electrical power supply, instrumentation and control, ventilation
Loss of utilities or of a functional sub-assembly in a test zone (during a transition phase from Test Zone (ZT) to Operating Zone (ZEXP) of new disposal cells and tunnels and underground sections)	Loss of utilities, fluids, energy, instrumentation and control or monitoring equipment

2.5.2 Preventive measures

The main principles for prevention of risks associated with the co-activity situations specific to Cigeo (Construction/Operation, Operation/Renovation and Operation/Maintenance) are as follows:

- a robust barrier between the ZEXP and the ZT underground: the design of the underground facility is based on the principle of installation of robust physical separations and total independence between the "operation" section (ZEXP) and the "construction" section (ZT) of the underground facility. These separations are dimensioned according to the various types of hazards likely to occur. Each zone has its own utilities networks, monitoring equipment, emergency and evacuation equipment. By design, the excavation, construction and equipping work are therefore performed within a closed worksite independent of the nuclear facility.
- phasing renovation periods. While regular maintenance is performed during operation, phasing of renovation or heavy maintenance operations, scheduled every 10, 20 and 40 years, allows these operations to be carried out by interrupting the main disposal package conditioning and transfer process.

During operation, the transfer of equipment intended for routine maintenance uses the Service ramp. The waste produced during these maintenance operations goes up via the waste package ramp. Most of this waste (mainly coming from maintenance of the nuclear ventilation) is produced during the annual shutdown phase of the facility and can be brought up outside of disposal operations to avoid interfering with the flow of casks. Co-activity situations are therefore very limited.

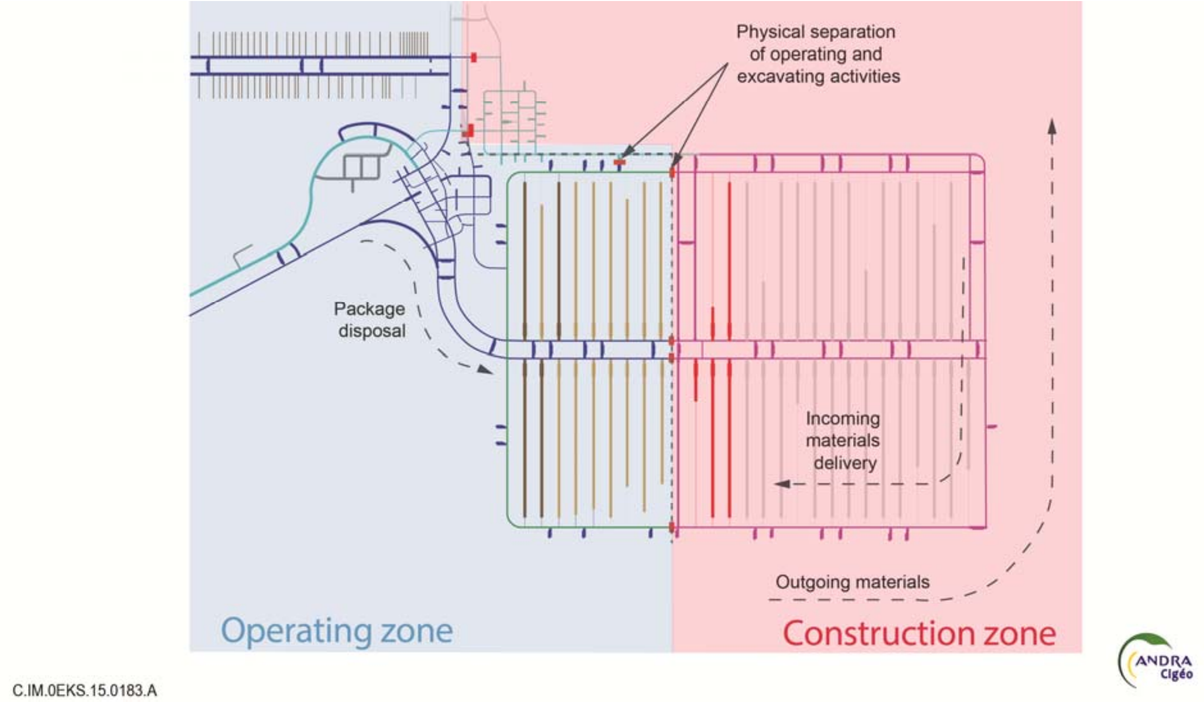

Figure 2.5-1 Schematic diagram showing the physical separations of operating activities and excavation of the underground facility

The prevention provisions associated with these principles are developed below.

2.5.2.1 Operation/Construction co-activity

Separation of activities

The physical separations between the operating zone and the construction zone are represented in Figure 2.5-1 **Erreur ! Source du renvoi introuvable.**above (in blue and pink, respectively). In addition, the "twin-tube" design of the connection drifts allows the first connecting drift to be assigned to incoming flows and the second to outgoing flows.

A maximum infrastructure is implemented prior to nuclear operation, in order to limit key construction that could take place during operation. The first connecting drifts and cells are constructed and brought into operation before startup of the nuclear activities.

During operation, the separation of the nuclear zone and of the construction zone is implemented by walls forming "airlocks". These airlocks contribute to the delimitation of the volumes ventilated by the nuclear ventilation systems (operating drifts) and conventional ventilation systems (construction drifts). The overpressure levels in the airlocks act as protected sectors (shelters for personnel in an accident situation), by guaranteeing the direction of air flow from inside the shelter airlocks to the outside.

The waste package ramp is used specifically for transferring waste packages in casks placed on the ramp transfer system, and for bringing up nuclear waste from maintenance (mainly from nuclear ventilation) to the surface. The service ramp is dedicated to other operating functions (emergency vehicles and services, emergency evacuation, procurement of maintenance equipment).

The creation of the facility with loop-shaped architecture including separate accesses (operating access and construction access) facilitates separation of the two zones and the associated flows.

Within a single zone, the risk of co-activity produced by flows of personnel, equipment or materials is also limited by a distribution of the flows in the surface-bottom connections with a separation by activity and, in particular:

- two shafts for the operating zone installed in ZEXP:
  - ✓ the VFE shaft (PN 064) dedicated to the transfer of "operating" personnel and to fresh air intake;
  - ✓ the VVE shaft (PN 071) dedicated to exhaust air return for the construction zone;
- Three shafts for the construction zone installed in ZPTV:
  - ✓ the VFT shaft (PT 065) dedicated to the transfer of "construction" personnel and fresh air intake;
  - ✓ the MMT shaft (PT 069) dedicated to the intake and removal of construction equipment and materials;
  - ✓ the VVT shaft (PT 070) dedicated to the exhaust air return for the construction zone.

Two separate logistics support zones (ZSLs) are designed, according to the same principle of physical separation: a "construction" logistics support zone in the construction zone and an "operating" logistics support zone in the operating zone (See Figure 2.5-2). The construction works on the two ZSLs and their commissioning are implemented before the start of the nuclear activities.

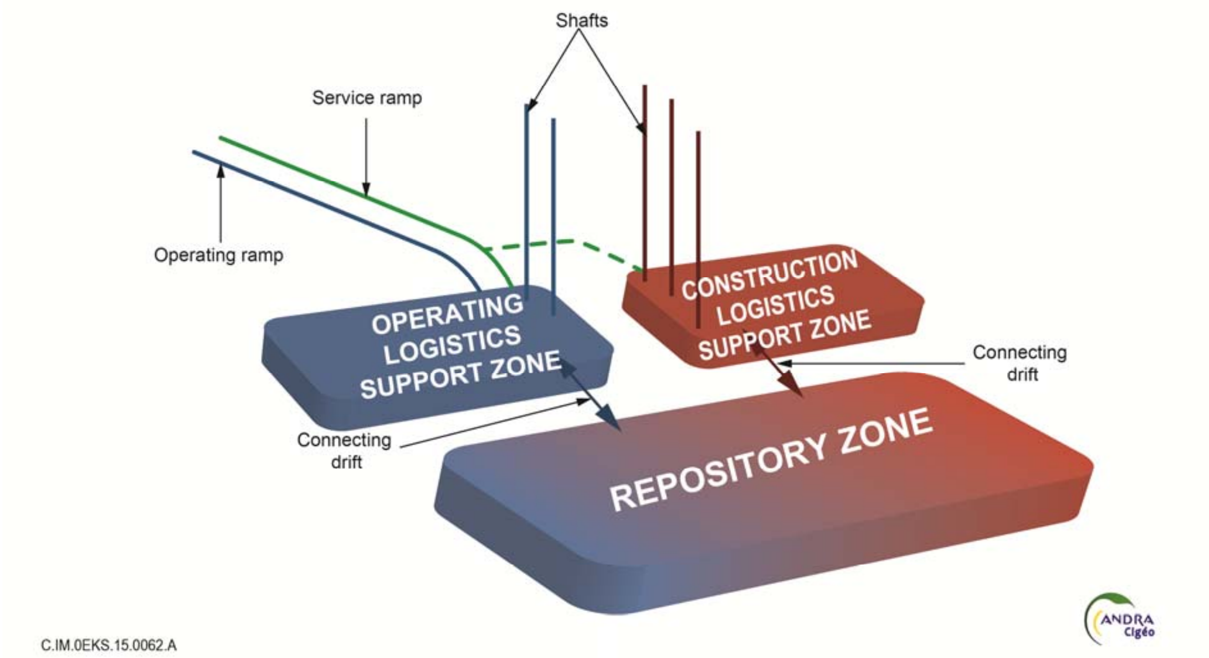

Figure 2.5-2 Organisation of Operating and Construction logistics support zones

Cross cuts, connecting drifts and access drifts for HLW and ILW-LL as well as the ILW-LL air return drifts under construction are separated from operating drifts by walls (see Figure 2.5-2) and, as needed, airlocks dimensioned to prevent any interference between zones, particularly in terms of circulation as well as the risk of fire spreading that might occur in construction zones on the nuclear zone, and vice versa.

<u>Deployment of structural construction</u>

During deployment of the facilities, the physical separations are moved as construction (conventional activities) and operating (nuclear activity) work progresses. This deployment is implemented in stages (T1 to TU). During the deployment phases and phases of transition from a Construction phase to an Operating phase, construction/operation co-activity cannot be prevented in these interfaces.

Gradual deployment of structures during time for each new section or disposal cell comprises the following phases:

- a construction phase;
- a phase of equipment installation, of connection to the operating and testing networks;
- an operating phase.

At this stage, the main technical and organisational provisions (see Chapter 3.6 of Volume II) specified for the design and deployment of underground architecture concern:

- the separation airlocks between the ZT and the ZEXP;
- the transition phase from a new section of the ZT to the ZEXP.

- ***The separation "airlocks" between the ZT and the ZEXP***

The positions of the physical separations and associated airlocks between the operating zone and the construction zone change as the deployment of the underground facility progresses:

- seven different successive positions of separations during the seven phases of deployment of the ILW-LL section (see Figure 2.5-3 and Figure 2.5-4) showing the change in the number of separations and their respective positions in 2031 and 2069);

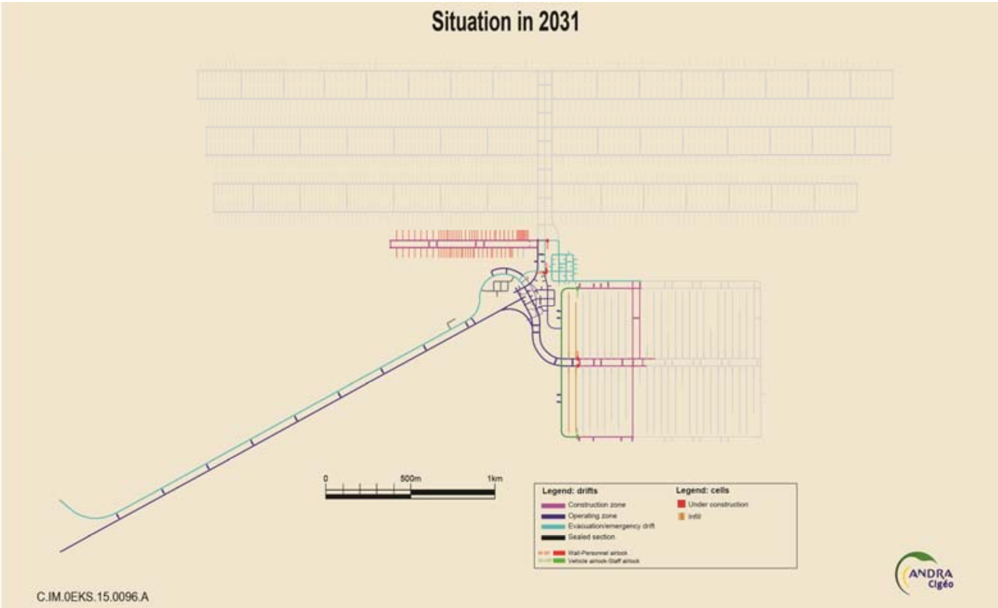

Figure 2.5-3 Schematic diagram showing the physical separations of operating activities and excavation of the underground facility

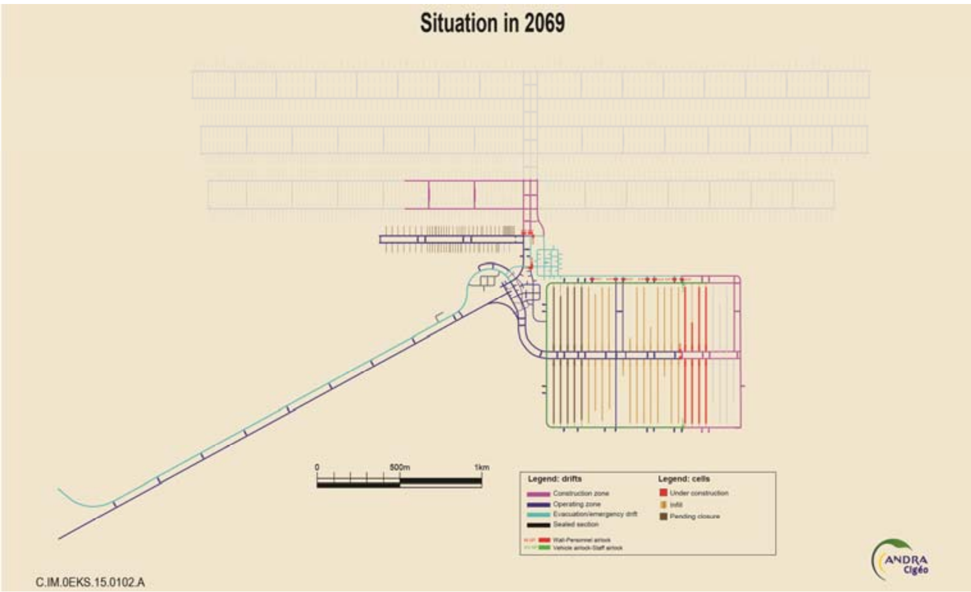

Figure 2.5-4 Schematic diagram showing the physical separations of operating activities and excavation of the underground facility

- seven successive positions during the construction of the six HLW1/HLW2 sections:
  - ✓ a first position up to 2069 (see Figure 2.5-4) between the HLW0 section and the construction of the first HLW1/HLW2 section;
  - ✓ and finally six successive positions during construction of the next five HLW1/HLW2 sections until they are commissioned (see Figure 2.5-5) illustrating changes in the number of separations and their positioning in 2113.

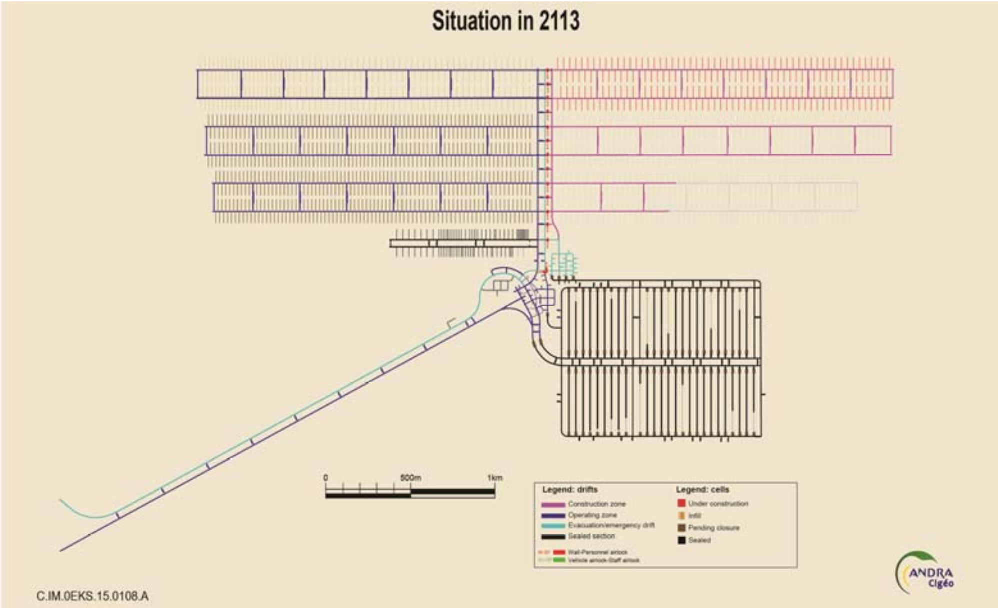

Figure 2.5-5 Schematic diagram showing the physical separations of operating activities and excavation of the underground facility

Two types of physical separation at the ZEXP/ZT interfaces are proposed with regard to their functions under normal conditions and under incident/accident conditions:

- for the twin-tube drift configurations (GLI ILW-LL, HLW0 and HLW1/HLW2, GA HLW0 and HLW1/HLW2), the interface comprises a physical separation and an airlock for personnel with compliance with the physical protection requirements (only emergency services are able to access the operating drift from a drift in the Construction Zone or emergency evacuation drift) (See Figure 2.5-6);
- for single-tube configurations (GRA South and North), the interface comprises a physical separation plus a personnel airlock allowing the passage of an emergency vehicle, to meet the requirement of having two access points for emergency teams, either through the operating zone or through the construction zone (see Figure 2.5-7). This separation must comply with the physical protection requirements.

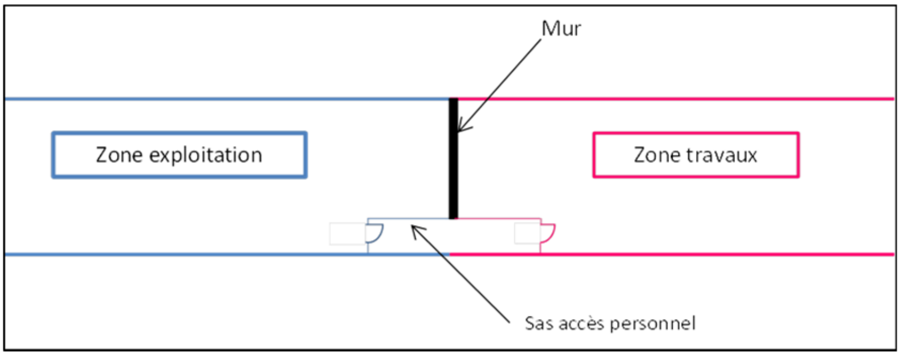

Figure 2.5-6 Graphical representation of the operation/construction interface –

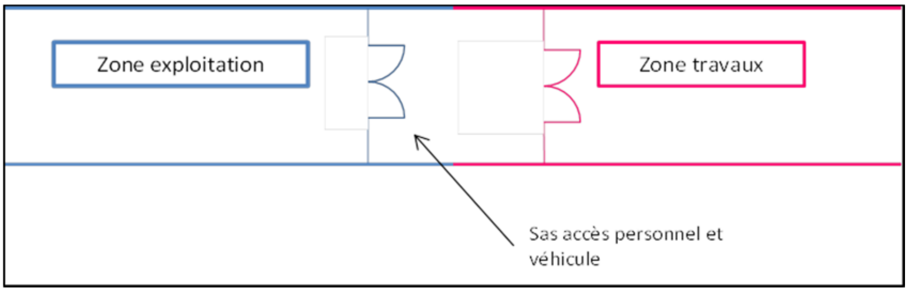

Figure 2.5-7 Graphical representation of the operation/construction interface - Single-tube configuration (GRA-ILW-LL)

These physical separations meet the following main requirements:

- fire resistance and reaction to fire to class REI 120. The adequacy of this requirement will be confirmed in the detailed engineering design phase with regards to equipment used nearby;
- leaktightness to prevent water from spreading from one zone to another in the event of floods with an internal cause;
- protection against impacts and collisions of equipment or vehicles used for handling, for example, by installing reinforced concrete slides at the bottom on either side;
- ease of deconstruction to allow the operating zone to be extended after qualification tests.

- ***The ZT to ZEXP transition phase***

Each phase of this deployment is performed in several stages, each taking place with the following objectives:

- maintain separation of the operating and construction activities;
- limit the influence of the operations to be performed, particularly on the zone in operation;
- prevent incident situations that lead to disruptions of ventilation, electrical power supply, instrumentation and control;
- prevent accident situations that could be harmful to the targets located nearby: persons at their work stations, physical separations, waste package transfer casks.

During the transition phase, the extension of the Operating Zone has three different statuses:

- the initial status corresponding to the initial ZEXP/ZT demarcation before the new phase of deployment of operation;
- the intermediate state that corresponds to construction of the following separations, thus defining an intermediate zone between the ZEXP and the ZT called the "Test Zone";
- the final state that corresponds to the new ZEXP/ZT demarcation once the Test Zone is transferred from the ZEXP side and the old separations are dismantled.

The provisions specified for extension of the operating zone from the initial state to its final state are a sequence of operations in accordance with the following process:

- construction of the civil works in the phase to be deployed in the presence of the physical separations described above;
- Routing equipment via the construction zone, installation and static tests of phase 1[64];
- isolation devices (e.g. valves, plugs, dampers), potentially duplicated on each side of the partition, are installed to guarantee independence of systems between zones up until transition;
- connection of the high-voltage range A (HVA) network (substation) to the main network in operation via sheathing placed in the drift invert;
- switching on equipment and connecting it to the "development and testing" network (CFI-CC); the development and testing platform (PDE) is a "mirror" CFI-CC facility of the instrumentation and control of the operating zone (servers, applications, etc.) allowing tests to be performed in the construction/test zone in "isolated mode" with no impact on operation;
- performing Phase 2 tests and qualifications [65] in isolated mode based on the PDE. The equipment is supplied with LV power from the definitive power supply networks (taken from the operating zone). The principle of complete selectivity of LV and HVA electrical facilities avoids any impact on operation in the event of an electrical fault during tests;
- transition from test zone to operation with:
  - ✓ construction, from the construction zone, of the physical separations at the edge of the test/construction zones (intermediate state);
  - ✓ the operations for removal of temporary devices, connection of new sections of network (ventilation, fluids, communications and security systems, etc.), of software migration of new equipment of the extended operating zone in the control room and of removal of physical separations at the boundary of the testing/operating zones (final state); it will be possible to perform this work with operation interrupted(to be confirmed during later phases);
- performance of tests in phase 3[66] consisting of global operating tests of the facility in the final inactive configuration. At this stage, it is planned for these tests to be carried out separately from operation, i.e. with no waste package disposal operations in progress in the deployed zone.

2.5.2.2 Co-activity in operation/maintenance

Preventive maintenance

The operations for regulatory inspections, routine testing and preventive maintenance are scheduled in advance.

The regulatory checks at monthly and quarterly intervals are performed outside operating hours and at the weekend.

[64] The phase 1 tests consist of end-of-installation checks.
[65] The phase 2 tests are tests of correct operation of components and subsystem.
[66] Phase 3 tests are overall facility performance tests.

The operations performed on a quarterly or annual basis take place during the weeks of shutdown of operation of the facilities. In particular they concern the equipment that is important for protection such as the firefighting circuits, the electrical installations, the lifting and handling equipment, the gas and steam pressure equipment. The incoming flows of transport containers and disposal flows of waste packages into cells are stopped. The whole of the nuclear process is stopped and disposal packages are waiting in the dedicated rooms of the surface facilities.

Corrective maintenance

The corrective maintenance operations (diagnostic of the cause of a failure of equipment, replacement of faulty parts, adjustments and reactivations, etc.) are unforeseeable and in some cases entail the shutdown of operation (for example, for the ramp transfer system). An analysis of the specific risks will be conducted before each intervention in order to be able to set up appropriate preventive and protective measures.

In the underground facility, when preventive or curative maintenance operations are performed without interrupting operation, the flows of personnel and equipment for maintenance can use the same route as the disposal packages (connecting and access drifts) and the operating personnel (ILW-LL air return drift to access filtration rooms to the rear of cells). The preventive measures for the associated risks are as follows:

- the speed of the bottom shuttles and carts is limited and their positions are indicated continuously in the control room;
- the casks are equipped with a geolocation device, as well as visual and audible indicators in order to alert the personnel to the presence of a disposal package undergoing transfer;
- movement of personnel is organised by the presence of either markings on the floor or separate protected paths;
- the service ramp, dedicated for use by maintenance equipment and emergency services, is separate and independent from the waste package ramp, which is dedicated for use for the nuclear process.

2.5.2.3 Co-activity in operation/renovation

Heavy maintenance or renovation operations take place regularly, about every 10 years, 20 years and 40 years. They require shutdown of the process during replacement of the equipment of the cells of the nuclear surface facilities (unloading, conditioning and inspection cells) or cask handling and transfer equipment, which limits the risks associated with the co-activity.

In order to limit shutdowns, these operations are scheduled between the various parties of the facility (surface nuclear facility, waste package ramp, operating shaft and ZEXP of the underground facility).

2.5.3 Monitoring systems

The parallel activities of operation/maintenance and operation/renovation do not require monitoring provisions in addition to those already present in the facility in relation to risk control.

Concerning the parallel activities of operation/construction, monitoring provisions are put into place for rapid detection of events that might particularly degrade the performances of the physical separations between the operating zone and the construction zone and compromise the applied requirement of a closed independent worksite.

The main provisions in relation to the risks identified are:

- fire detection set up in ambient conditions on each side of separations, in addition to on-board fire detection systems on vehicles and detection by operating personnel;
- detection of radiological ambient conditions on each side of the separations;
- detection of the presence of water on each side of the separations.

2.5.4 Mitigation measures

This section focuses on mitigation measures associated with parallel operation/construction activities.

The design and management of the physical separations (walls and airlocks) between the operating zone and the construction zone provide protection concerning accident scenarios that may occur on either side. The main associated provisions are presented below.

2.5.4.1 Provisions concerning the risk of fire

Fire resistance/compartmentation

The constructive provisions (airlock/wall separating conventional/construction zones of the nuclear zone), the limitation of fire loads of vehicles/equipment close to the interfacing zone and the distance of these vehicles /equipment from the walls or airlocks of at least 30 metres (installation of physical barriers) prevent the spread of fire from one zone to another, and mitigate the impact of a fire in the construction/conventional zones on the nuclear zone.

The fire resistance classification of walls/airlocks shall be at least REI or EI 120 (for conventional fires). If necessary, designing to the HCM curve could be considered for the airlock located on the worksite side, for additional qualification if the distance between the fire and the airlock/wall is found too restrictive.

Evacuation of personnel

Given the large number of construction personnel at the bottom compared with the evacuation routes to the surface, no direct evacuation to the surface is authorised when an alert is triggered.

Evacuation therefore consists in sheltering the personnel, pending further instructions or emergency team intervention for an organised and accompanied evacuation to the surface. The personnel gather at assembly points located in areas allowing evacuated persons to be rapidly counted, without obstructing the arrival and action of emergency services.

In a fire situation, each zone has its own routes for evacuation of personnel. The evacuation of personnel takes place within the accident zone (in ZEXP or ZT) independently of the other zone and does not rely on crossing the separations located at interfaces. However, in the case of a fire situation not allowing for secure evacuation of personnel in the correct zone, the physical separations are dimensioned such that, as an exception, evacuation of personnel from the operating zone via the construction zone (and vice versa) is possible with use of the personnel airlocks located at the operation/construction interfaces. These airlocks will need to comply with the principles of physical protection.

Intervention and firefighting

Any vehicle with a significant potential fire load will be equipped with on-board automatic fire-extinguishing coupled with fire detection. In all cases, the vehicles are equipped with portable fire extinguishers in sufficient numbers.

Extinguishers are installed not only to save lives, but also to mitigate the impact on safety targets. In addition to the physical separations between construction/conventional zones and nuclear zones, portable emergency equipment (fire extinguishers, etc.) available to operators are can be used to restrict the development and spread of the fire from its starting point.

firefighting and emergency response resources include:

- fixed extinguishing systems (on the constructions side, these systems must be easy to move and to disassemble and are supplemented by mobile equipment);
- an emergency response group with an operational firefighting organisation appropriate for the underground environment;
- underground firefighting systems; a wet system is preferable to a dry system in relation to the immediate availability of water allowing speed of intervention and firefighting that are essential in order to control a fire (feedback from firefighting in drifts);
- firefighting vehicles;
- extinguishing chemicals recovery systems.

The selection of extinguishing agents must prioritise effectiveness and the reduction of water consumption (water mist, foam, etc.).

The emergency intervention operational organisation follows these key principles:

- the emergency team members form an integral part of the operating and works personnel. Depending on the accident and in the event of failure of the first intervention, the second intervention team ensures protection of people and tackles the accident whilst awaiting the arrival of the emergency services;
- the emergency services arrive to take over from the second response team, who pass on information from their reconnaissance of the situation.

In order to ensure rapid response in the underground facility, safety cabinets used to store protective and firefighting equipment are located in the cross cuts/shelters/recesses.

In the twin-tube configuration, the intervention teams and emergency services use the unaffected drift then go through a cross cut airlock to reach the affected zone. In the construction zone, cross cuts to guarantee the twin-tube drift configuration are to be built as soon as possible. Emergency response vehicles can go through the evacuation/emergency cross cuts.

For single-tube configurations, the smoke doors (compartmentation) are used under manual or automatic control to limit the spread of fire and smoke in the underground structure and thus make it easier for emergency response teams and emergency services to approach the scene of the accident.

Emergency vehicles access in the construction zone must be not impeded by obstacles. The solutions considered to meet this requirement are as follows:

- vehicle tracking and communication with drivers to inform them of the procedure to follow to clear the way for emergency vehicles in the event of fire;
- vehicle parking authorised on one side only;
- limitation of number of mobile shelters in zones close to the excavation face;
- limitation of temporary disposal zones in cross cuts and marking out these zones to avoid obstacles;
- traffic plan to minimise U-turns and crossed flows.

In a fire situation, emergency response operations are carried out within the accident zone (in ZEXP or ZT) independently of the other zone, and does not require crossing the separations located at interfaces. In the case of single-tube drifts, emergency services must be able to be intervene on either side of the accident zone by driving through the airlocks between the construction and operation zones. These airlocks shall comply with physical protection requirements.

2.5.4.2 Provisions regarding nuclear risks

The provisions taken regarding the dispersion of radioactive materials have led to the classification of the drifts as category I-C1 (very low concentration in accident conditions). These drifts are the only ones that interface with the construction zone drifts. They are physically separated and independent from the point of view of ventilation, which removes any risk of contamination of the construction zone.

In terms of external exposure, the transfer of packages inside casks designed to ensure radiation protection limits the dose rate at one metre from the cask. The thickness of the physical separations combined with the distance of the cask from these separations during transfer rules out any effect on personnel located in the construction zone.

2.5.4.3 Provisions for flooding

In addition to the provisions applied for prevention of flooding in the underground facility, the following provisions are applied to limit the effects of such flooding:

- the physical separations are leaktight in order to prevent water from construction disrupting the zone in operation and vice versa;
- a gravity-driven system for recovery of water equipped with detectors at the lowest point and with lift pumps.

2.5.4.4 Provisions for earthquake

The physical separations of the operating zone and the construction zone are designed to withstand a safe shutdown earthquake in order to remain stable in the event of an earthquake. The equipment located close to the separations is also designed to withstand a safe shutdown earthquake to prevent projectiles liable to damage the separations.

2.6 Risks of malicious acts

Risks of malicious acts are associated with deliberate attacks that could affect facility safety during the operating phase, carried out by individuals inside or outside the Cigeo organisation. The threats taken into consideration for the risks of malicious acts are:

- theft or misappropriation of nuclear materials for purposes including, in particular, production of thermonuclear devices;
- acts of sabotage or attacks that may present a health or environmental hazard by dissemination of radioactive materials, irradiation or toxic releases associated with nuclear activities;
- actions that might prevent operation of the facilities and be harmful to the economic potential of the Nation.

The Cigeo facility is a nuclear facility and, as such, presents potential risks associated with malicious acts. For this reason, it is subject to regulations on the protection and control of nuclear materials located at facilities and during transport.

The malicious acts may be targeted at radioactive materials (or nuclear materials) or equipment, loss of which might lead to radiological impacts on the public.

In general, the risk of malicious acts is managed by means of a physical protection device and a system for managing and monitoring nuclear materials. They are established on one hand in relation to the regulations concerning these subjects and on the other hand in relation to the nature of the materials, their conditioning and the process of their disposal.

The main regulatory texts governing the Cigeo organisation in relation to risks of malicious acts are:

- the EURATOM non-proliferation treaty;
- the agreement on the physical protection of nuclear materials;
- the Defence Code, Section III: economic defence in Articles L. 1332-1 et seq. (grouped together in Chapter 2: protection of facilities of vital importance) and L. 1333-1 et seq. (grouped together in Chapter 3: nuclear facilities and materials).

The main defence elements integrated into the physical protection device are:

- restriction of access to authorised personnel; the clearance levels may differ depending on whether they are for access to the site generally or for access to the sensitive zones of the facility;
- The definition of these zones is based on the recommendations of the Order of 10 June 2011 concerning physical protection (37);
- performance of the excavation, construction and equipment work are therefore performed within a closed worksite independent of the nuclear facility;
- classification of certain data concerning physical protection and safety of the facility;
- implementation of monitoring provisions for prevention, detection and alerting security personnel to any anomaly concerning risks of malicious acts;
- setting up of successive barriers separating the targets from the outside of the facility and allowing gradual reinforcement of the protection in relation to the risks of malicious acts;
- setting up of an organisation involving active participation of the Cigeo security personnel as well as the public authorities in order to allow responsive actions in the event of a hazard occurring;
- compliance with the regulations in relation to physical protection and to monitoring and accounting for nuclear materials.

The physical protection device will undergo robustness analysis during a safety study that will check its efficiency through a series of predefined malicious act scenarios.

2.7 Risks associated with "full" tunnels awaiting closure

2.7.1 ILW-LL disposal cell

2.7.1.1 Reminder of phases of life of the disposal cell

During operation, at the end of the APS, two main life phases are identified for the ILW-LL disposal cells (see PDE(7)):

- a ventilated phase from the time the tunnel starts operating until the ILW-LL section is closed (i.e. a period of about 70 years). During this phase, steps are taken to ensure a constant ventilation flow rate, equal to that required during the filling phase;
- a non-ventilated phase up to the end of the facility operating phase (about 50 years).

2.7.1.2 Consequences concerning main risks

<u>Dispersion risk</u>

The principles of containment shown in Section 2.1.2 are valid for the ILW-LL disposal cell throughout the period of operation.

When the disposal cell is ventilated, the containment systems are the same as for operations of placement in disposal (see Section 2.1.2), i.e. disposal packages as the primary containment system and the civil works of the disposal cell combined with nuclear ventilation as the secondary containment system.

When the disposal cell is no longer ventilated, the two containment systems applied are:

- disposal packages as primary containment system;
- the civil works of the disposal cell combined with a closing structure (static containment of the cell) as the secondary containment system.

The normal operating range of the disposal cell takes the following into consideration:

- a possible release of radioactive gases;
- an absence of dispersion of radioactive aerosols contained in the disposal packages.

Once the ILW-LL disposal cell is filled and no operation is performed, the design of the disposal packages and favourable ambient conditions in the ILW-LL disposal cells are such that the loss of containment in a significant number of disposal packages in the ILW-LL disposal cell before the end of the operating phase is impossible. However, degradation of a limited number of disposal packages, with particles being suspended in the air in the disposal cell, is taken into consideration. A situation leading to atmospheric contamination above 1 LDCA in the ILW-LL disposal cell could nevertheless be managed by the tunnel ventilation system continuing to fulfil its dynamic containment role (class C2) then, when the tunnel is no longer ventilated, by the static containment ensured by the tunnel and a closure structure. More specific provisions, still under research at this stage, can also be made if later studies confirm their necessity, for example: installation of upstream filtration on the duct opening to the cell or reinforcement and/or securing the filtration downstream in the last filtration stage room, provisions to ensure that dynamic containment is maintained, removal of this/these waste packages according to a specific operating mode.

One or more waste packages showing signs of impaired containment may be removed using the transfer cask, which then contributes to the containment of radioactive substances. The leak rate of the cask is then compatible with the transfer of waste packages until a maximum level of removable surface contamination is reached. If necessary, specific provisions, currently still under research, could be made before removing the waste package from the handling cell (fixing contamination, etc.).

<u>With regard to external exposure risk</u>

Once the disposal cell is filled, radiological protection is provided by a wall of concrete blocks placed at the head of the usable part of the disposal cell between the last row of waste packages and the protective door of the handling cell. This protection is designed on the basis of the radiological zoning adopted for disposal cell closure and package recovery operations. In particular it allows for the dismantling operations for the radiation protection door and associated equipment to be performed as soon as emplacement in the disposal cell has been completed.

A radiation protection wall is also installed at the back of the disposal cell.

<u>Concerning the risk associated with radiolysis of waste</u>

During the ventilated phase, nuclear ventilation continues to ensure that the radiolysis gases produced by the waste packages are removed.

During the non-ventilated phase, provisions will be applied, such as inerting, in order to counter a risk of an explosive atmosphere forming.

<u>With regard to heat transfer risk</u>

Since the ventilation does not contribute to the heat removal function, the change to the non-ventilated phase has no impact on this protective function.

2.7.2 HLW cell

As soon as a disposal cell is full, a radiation protection final closure plug is placed inside the sleeve of the cell as close as possible to the packages inside. This is left in place until the time of transfer to level III and remains in place during cell closure. It is designed on the basis of radiological zoning adopted for cell closure and package retrieval operations and in compliance with dose rate objectives in an HLW disposal cell access drift.

The system for removing water and, where applicable, corrosion products, remains operational until the clay plug is installed (transfer to level III).

2.8 Risks associated with retrieval operations

The retrieval scenarios concern the retrieval of certain waste packages that have just been - or are in the process of being - placed in the disposal facility; this retrieval is considered useful for Cigeo and forms an integral part of this operation (see DOREC (8)). The basic necessary operations for implementing the retrieval scenarios correspond to the normal operating conditions of the facility.

These retrieval scenarios are carried out occasionally, on a limited number of waste packages, in disposal cells where all handling equipment is operational, i.e. the cells/tunnels are either being filled, or, when filling is complete, waiting to be mothballed or for their handling equipment to be removed. This latter phase is expected to last about one year after completion of filling.

For this category of retrieval scenario, the safety assessment is equivalent to that of the waste package disposal operations. At this stage of the project, the safety options for the corresponding operations described in this volume also cover the operations of retrieval scenarios.

2.8.1 Retrieval of a disposal package taken to the surface

This scenario considers taking an ILW-LL or HLW disposal package in the disposal cell, bringing it up to the surface and placing it in the deconditioning cell.

2.8.1.1 ILW-LL disposal package

All the necessary handling and monitoring equipment is operational. The operating disposal cell is accessible without any special provisions.

All the handling systems involved in the disposal package retrieval cycle are those used for placing in disposal.

The disposal package is considered accessible, with no signs of deterioration that would risk compromising gripping and transfer of the waste packages by the various types of handling equipment. The retrieved disposal package is "not contaminated". A system for checking the waste package for contamination is installed in the handling cell before loading into the cask. If necessary, a system for fixing the contamination can also be installed.

For this scenario, the safety provisions made for disposal include retrieval operations with no need for special precautions or supplementary provisions. The handling speeds and heights are equivalent to those of emplacement in disposal.

2.8.1.2 HLW0 disposal package

As with the ILW-LL scenario, it is considered that:

- all of the necessary handling and monitoring equipment is operational;
- the cell in operation is accessible without any special provisions;
- the disposal packages are considered accessible, with no signs of deterioration that would risk compromising the gripping and transfer of the waste packages by the various types of handling equipment;
- the retrieved disposal package is "uncontaminated", therefore no contamination inspection is performed before placing it in the cask in the cell and transferring it to the surface.

Retrieval of an HLW0 waste package from the cell is performed using a puller robot (as opposed to the pusher robot for emplacement). All the other handling systems involved in the disposal package retrieval cycle are those used for placing in disposal.

Concerning emplacement in disposal, the temperature of the cell head and the disposal package are higher than those at disposal due to the expected increase in temperature of the filled cell. However, the equipment is designed to operate within a wide range of temperatures covering this situation. The safety provisions made for disposal include retrieval operations with no need for special precautions or supplementary provisions.

2.8.2 Removal of packages transferred into another cell

This scenario considers the removal of an ILW-LL or HLW disposal package from one cell and transfer of it to a second cell.

2.8.2.1 ILW-LL disposal package

It is considered that:

- all of the necessary handling and monitoring equipment is operational. The cells are accessible without any special provisions;
- the disposal packages are considered accessible, with no signs of deterioration that would risk compromising gripping and transfer of the waste packages by the various types of handling equipment;
- the moved disposal packages are considered to be "uncontaminated", a disposal package contamination inspection system is installed in the handling cell before placement in the cask and transfer to the second cell.

The safety measures taken for disposal include retrieval operations without requiring special precautions or adding additional measures. The handling speeds and heights are equivalent to those of emplacement in disposal. The reception cell is considered compatible with the temporary presence of disposal packages that have been moved.

2.8.2.2 HLW0 disposal package

It is considered that:

- all of the necessary handling and monitoring equipment is operational. The disposal cells are accessible without any special provisions;
- the disposal packages are considered accessible, with no signs of deterioration that might compromise gripping and transfer of waste packages by the handling equipment;
- as the disposal packages being moved are considered "uncontaminated", no contamination inspection is performed before they are placed in the cask at the disposal cell and transferred to the second cell.

Concerning emplacement in disposal, the temperature of the cell head and the container are higher due to the expected increase in temperature of the filled cell. However, the equipment is designed to operate within a wide range of temperatures covering this situation. The safety provisions made for disposal include retrieval operations with no need for special precautions or supplementary provisions.

2.9 Acknowledgement of operating experience feedback

As part of the Cigeo project design, the feedback from past events in similar facilities or on similar equipment must be analysed to obtain information that could be relevant for the project. In addition, this analysis meets the requirement of the French Nuclear Safety Authority as stated in the Order of 7 February 2012 laying down the general rules for basic nuclear installations, in particular Article 2.4.1, paragraph 3, which requires collection and analysis of operating experience feedback.

The purpose of this section is not to provide an exhaustive description but rather to target the most important feedback in relation to the specific characteristics of Cigeo. It is also important to note that the design options and provisions for control of risks proposed at the end of the basic engineering design phase (APS) and described in the previous sections favour robust and proven provisions based on the feedback from their use at existing facilities.

2.9.1 Feedback concerning fires in an underground environment

There are many aspects of the underground environment such as the drilling of road and rail tunnels and drifts, the layout of sanitation networks, the work in basement car parks, excavations of underground quarries and mines.

In this confined environment, the conditions (noise, air pollution, lighting, lack of space, humidity, cold) in which activities are performed make daily work and risk management difficult.

Safety in a facility in an underground environment is crucial, with the primary objective, on one hand, of reducing accidents as much as possible, and on the other, in the event of accident conditions, of saving human lives as well as the equipment/structures necessary for operation of the facility (partial or complete destruction of the damaged structure).

The major hazard in this type of infrastructure is that of fire. Underground space can make it difficult for people to move freely and for smoke and heat to be removed.

This has been demonstrated dramatically in some catastrophic fires that have occurred over the last few decades. These severe accidents, particularly in tunnels, have led to a greater awareness of these issues and have resulted in many new initiatives, and new regulations in particular, aiming to improve fire safety.

As part of the Cigeo project design, the feedback from major fires in underground structures must be analysed to obtain information that could be relevant for the project:

- Rail tunnels
  - ✓ Channel tunnel;
  - ✓ Paris subway;
  - ✓ South Korea subway;
- Road tunnels
  - ✓ Mont Blanc tunnel;
  - ✓ Tauern tunnel;
  - ✓ Gothard tunnel;
  - ✓ Frejus tunnel;
- Passenger transport tunnel
  - ✓ Kaprun ramp transfer system;

- Worksite tunnels
  - ✓ EOLE RER E worksite;
  - ✓ A86 tunnel worksite;
- Service tunnels
  - ✓ Paris 13th arrondissement service tunnel;
- Quarries
  - ✓ gypsum quarry: Montmorency gypsum quarry;
- Repository
  - ✓ for chemical waste: Stocamine (Alsace potassium mine);
  - ✓ nuclear: The Waste Isolation Pilot Plant (WIPP) in US.

The lessons learned from these accidents provide guidance on the best practices for the future construction and operation of Cigeo and, more especially, for the underground infrastructure: surface-bottom connections including the waste package ramp, service ramp, shafts and underground facility (ZSL, disposal sections).

For each event considered, a concise description of the facility, an analysis of the fire(s) and a summary of the lesson learned from the accident have been produced (38)

For example, the lessons learned from underground waste disposal facilities abroad, taking into account their specific characteristics, provide useful material for Cigeo design.

These are shown in the table below.

Table 2.9-1 Lessons learned from accidents occurring in underground waste disposal facilities

	Risk factors			Cigeo
	Events	**Consequences**	**Lessons**	
General provisions	Fire outbreak due to non-compliant waste packages	Acceptance of non-compliant waste packages	Quality control for waste packages for disposal, from conditioning to emplacement	Specification for acceptability of waste packages Waste package inspection programme
	The preventive and corrective maintenance programme did not prevent or correct the accumulation of flammable material on the salt truck. There is a clear difference in maintenance between the vehicles carrying waste and the vehicles in the construction zone.	Fire outbreak	Revision of the maintenance programme	Maintenance programme
	A pit nuclear counter-culture exists where there are major differences in maintenance of equipment between the nuclear zone and the worksite zone.	Maintenance fault on worksite part	Revision of the maintenance programme Development of an identical culture for the nuclear and worksite zone	Maintenance programme Separation of nuclear zone and worksite zone.
	The quality assurance system of the contractor, NWP (CAS) failed to identify the conditions and deficiencies of the maintenance programme that caused this event.	Maintenance fault	Revision of quality programme	Maintenance programme Integrated management plan
	The Carlsbad DOE (CBFO) external office failed to implement the monitoring programmes that identified the weaknesses of the contractor, NWP CAS, and the conditions associated with the primary cause of this event.	Fire outbreak	Revision of the monitoring programme	Maintenance programme Integrated management plan
	There are elements of the conduct of the operations (CONOPS) that demonstrate a lack of rigour and discipline	Difficult evacuation, Personnel not wearing protective equipment during evacuation, fire door locked	Revision of the monitoring programme	Maintenance programme Integrated management plan Regular training sessions and exercises for on-site emergency team and with outside emergency personnel.
Fire detection and firefighting provisions	Fire in disposal package in block 15	Several attempts at extinguishing using different extinguishing equipment	Adapting emergency resources	Emergency equipment appropriate to the risks and distributed within the facility. Personnel training.
	Long and difficult reconnaissance Lengthy emergency response operations	Limited number of specialists available	Need for specialist support in underground emergency response	PUI Regular training and practice in particular with external emergency services (agreement with the SDIS 55 and 52)
	The firefighting programme has not been very satisfactory in relation to the higher level requirements concerning vehicle fires, in terms of activation of the firefighting system	Fire not extinguished	Revision of extinguishing devices	Emergency equipment appropriate to the risks and distributed within the facility. Personnel training.

	Risk factors			Cigeo
	Events	**Consequences**	**Lessons**	
	Accumulation of combustible materials in the underground section in quantities exceeding the limits specified in the Fire Hazard Analysis (FHA) and implemented procedures.	Risk of fire spreading	Fire load management	Limiting and monitoring fire loads
	Operator training and qualification was insufficient to provide an adequate response to a vehicle fire. *	Fire outbreak Fire not extinguished	Revisions of training programmes	Regular training sessions and exercises for on-site emergency team and with outside emergency personnel.
	CMR response to fire, including assessment and protective measures, was less than satisfactory.	Diffusion of smoke in the facility	Revision of CMR procedures	Regular training sessions and exercises for on-site emergency team and with outside emergency personnel. Ventilation control procedure
	The emergency/preparation programme and response were ineffective.	Inadequate emergency management	Revision of emergency programme	Regular training sessions and exercises for on-site emergency team and with outside emergency personnel. Common emergency management centre
Provisions aimed at preventing fire from spreading and limiting its consequences	The FHA did not provide a complete analysis covering all credible underground fire scenarios, including a fire located close to the air intake shaft.	Fire outbreak	Revision of fire hazard studies	Exhaustive analysis of risks and defence-in-depth.

Underground fires are generally particularly difficult to deal with: a long time required for emergency operations due to the confined environment and also the length of facilities. Depending on the fire load involved, the presence of a varying number of people and the instructions deployed, they can have consequences in terms of significant human and material impact. The tragedies that have occurred in the road tunnels of Mont-Blanc, Tauern, Gothard, Fréjus in France, not forgetting the Kaprun ramp transfer system tunnel (in Austria) and the Daegu subway (in South Korea) have been clear examples of this.

Feedback from fires that took place in deep waste repositories show the inherent difficulties for interventions involving fire in deep underground environments in the presence of hazardous products.

These accidents have clearly highlighted the risks associated with a fire. One of the key risks is the extremely fast development of some fires in particular on trucks, with a considerable increase in temperature, possibly in excess of 1000 °C. This feedback will be used for the design and use of the construction zone of the facility.

Experience has also shown that substantial quantities of toxic gases and smoke can be produced in a short time even from the very start of the fire. It is also apparent that the human factor associated with the behaviour of operators and intervention teams was not always as expected.

The feedback from fires in various facilities has resulted in changes to regulations specific to their respective fields. These regulations are used for Cigeo either directly in the construction zones, or through the fire baseline for design conception (6) in the nuclear operating zones.

It has also shown how useful it is for designers of new facilities, to integrate the fire risk from the start of their projects.

This feedback is largely already taken into account in the context of the Cigeo project and monitoring of national and international accidents is ensured internally by Andra.

2.9.2 Feedback concerning ageing

Ageing of facilities is a major cause of industrial accidents. According to the BARPI, in France, there have been about fifty accidents occurring since 1990 in various industrial fields. In the nuclear field, two accidents were recorded:

In 2006, in a conversion plant for uranium ore, the internal corrosion of a pipe resulted in the formation of holes in piping leading to leakage of chemicals into the river downstream;

In 2009, a break in the underground piping in a research centre caused seepage of effluents into the soil. The leak was due to ageing of the underground piping, and the break was associated with a lack of monitoring and maintenance due to the low accessibility.

However, a technical assessment by the Committee on the Safety of the Nuclear Installations (CSNI) proposes management of ageing of the facilities of the fuel cycle. The principles of management of this phenomenon and the good practice indicated in this technical assessment are used for Cigeo and are shown in the dedicated section for risk associated with ageing.

In all industrial sectors, long-term availability of printed circuits and electronic components is a genuine challenge, since the lifetime of an electronic component is shorter than ten years. With other major French industries, AREVA has put together a committee responsible for the obsolescence of the electronic components in order to manage the means necessary for equipment production and software updates. For the components that are no longer available on the market, a common platform has been created in order to implement reverse engineering, reconstruction and insertion of components into the original older technological environment. Internal training was organised from 2002 based on the information learned from use of the facilities, in order to maintain the knowledge and the control of the whole of the instrumentation and control architecture.

Civil works concrete and that of the various other structures, both at the surface or underground, may be the site of a degradation process associated with pathologies such as internal and/or external sulfate attack. The available feedback for reducing these degradation and ageing phenomena will be used in the various phases of design and construction. In addition, during operation, the concretes will be subject to a ten-yearly examination and special monitoring, the state of the civil works contributing to safety functions can be assessed by a visual examination.

2.9.3 Feedback from the Underground Research Laboratory

The safety options and design provisions are based on feedback from the Underground Research Laboratory, which is described in particular in reference (39).

2.9.4 Feedback from technological tests

The safety options and design provisions are based on the one hand on feedback from the technological tests performed on disposal containers (see Volume II) and on prototypes for handling and transfer of disposal containers and, on the other hand, on closure devices of structures (backfills and seals), and lastly on information acquired as part of European projects (example of ESDRED, MODERN, DOPAS, LUCOEX…).

3

Study of design-basis situations

3.1 Study of design-basis situations

The safety approach requires verification that sufficient measures are taken to guarantee compliance with the safety functions. This verification is carried out by identifying incident and accident operating situations and estimating the radiological consequences of the installation's bounding scenarios in terms of releases.

The various design-basis situations identified by the risk assessment are presented below. The design-basis situations are presented according to the breakdown between surface nuclear installations and the underground installation. The radiological consequences of the bounding scenarios are presented in Section 3.1.3.

3.1.1 Presentation of incident situations

The incident situations identified for surface nuclear installations and the underground installation are presented in Table 3.1- and Table 3.1- respectively.

Table 3.1-1 Incidental situations for surface installations

No.	Area	Scenario
I1	Train/truck bay	2 m fall of an ET-V or ET-H container being handled on the gantry crane during the transhipment from the train to the rail lorry as a result of human error
I2	Receiving area no. 3 for ET-H	1.2 m fall of an ET-H container being handled on the bridge crane during the transhipment to the cart as a result of human error
I3	Cask storage area	Collision/tipping over of a HLW or ILW-LL cask

Given the transfer speeds of the machinery and the robustness of the cask, scenario I3 does not constitute a hazard for the package liable to lead to radioactive substances being placed in suspension. Scenario I1 envisages a larger drop height than the other scenarios, thus liable to mobilise a larger source term and it is therefore considered to be bounding scenario in terms of radiological consequences. The detailed description of Scenario I1 and the estimate of the corresponding radiological consequences are presented in Section 3.1.3

Table 3.1-2 Incident situations for the underground installation

No.	Area	Scenario
I4	ZSL, connecting drifts	Collision/tipping over of a HLW or ILW-LL cask

Given the transfer speeds of the machinery and the robustness of the cask, this scenario does not constitute a hazard for the package liable to place radioactive substances in suspension.

3.1.2 Presentation of accident situations

The accident situations identified for surface nuclear installations and the underground installation are presented in Table 3.1- and Table 3.1-respectively.

Table 3.1-3 Accident situations for surface nuclear installations

No.	Area	Scenario
A1	Process building	Military aircraft crash
A2	Underground installation exhaust air extraction shaft	General aviation aircraft crash
A3	Train/truck bay and receiving area no. 3 for ET-H	Lorry fire involving a transport container (ET)
A4	Receiving area no. 2 for ET-V	Fall < 6 m of an ET-V container without cover being handled on the bridge crane, when it is tilted into the pit
A5	Preparation and docking hall	Fire on the cart and transfer carriage involving a type B ET without cover and without lid
A6	Unloading cell	Six metre fall of a CP unloaded with the bridge crane from an ET-V following hardware failure of the lifting chain
A7		Fire on the cart involving a primary package at the inspection station
A8	ILW-LL/HLW conditioning cells	Fire on the cart and the conditioning station involving an unprepared disposal package
A9	Process circulation corridors	Fire on the cart and transfer carriage involving a disposal package
A10		Fire on the cart and transfer carriage involving a CP
A11	ILW-LL cask loading cell	1.2 m fall of a disposal package being handled on the bridge crane, following a hardware failure of the lifting chain
A12	HLW cask loading cell	3 m fall of a disposal package
A13	Ramp transfer upper station	Fire on the shuttle, electrical cabinets, ramp transfer system (hydraulic capacity + electrical cabinets)

Given the source terms liable to be mobilised, Scenarios A6 and A7 cover the other scenarios in terms of radiological consequences. The detailed description of the scenarios and the estimate of the corresponding radiological consequences are presented in Section 3.1.3

Table 3.1-4 Accident situations for the underground installation

No.	Area / zone	Scenarios
A14	Ramp transfer lower station	Low-speed collision at the ramp transfer lower station
A15	Underground drifts	Cart fire involving a cask
A16	ILW-LL handling cell	Fall of a disposal package following an elevator failure
A17		Fire in a handling cell
A18	ILW-LL disposal cell	Fire on the disposal package crane involving a disposal package
A19	HLW disposal cell	Fire on the pusher-jack (+ steel sleeve + HLW disposal package) in the HLW cell

Given the source terms liable to be mobilised, Scenarios A16 and A17 cover the other scenarios in terms of radiological consequences. The detailed description of the scenarios and the estimate of the corresponding radiological consequences are presented in Section 3.1.3

3.1.3 Study of bounding scenarios

3.1.3.1 Calculation hypotheses

The impact calculations are carried out using the CERES® radiological impact platform developed by CEA.

The impact of the accidents is calculated for three sets of meteorological conditions:

- DF2: low diffusion conditions, wind speed 2 m.s-1, no rain;
- DN5: normal diffusion conditions, wind speed 5 m.s-1, no rain;
- DN5P: normal diffusion conditions, wind speed 5 m.s-1, rain during release.

A single meteorological condition is to be considered for the duration of the release, defined by a stability class (low diffusion or normal diffusion), a wind speed and rain intensity.

The population categories considered are a one- to two-year-old child a ten-year-old child and an adult.

The impacts are calculated at:

- 500 m corresponding to the distance to the site fencing;
- 1,000 m corresponding to the distance between Saudron and the EP1 building discharge stack;
- 2,000 m corresponding to the distance between Bure and the underground installation discharge stack (VVE shaft) for accidents in the ILW-LL cells.

Two impact assessments were carried out:

- short-term impact, corresponding to the committed effective dose during the accident received by the public at the site fencing, at a distance of 500 metres;
- a long-term impact, corresponding to the committed effective dose received by the public (50 years for an adult and 70 years for a child) at distances of 1,000 and 2,000 metres.

The release heights depend on the location of the scenario:

- at ground level for the train/truck bay;
- 17 m for the surface nuclear installation discharge stack for the ramp zone (EP1);
- 12 m for the underground installation discharge stack (VVE shaft);
- 12 m or 17 m depending on the ventilation system concerned (surface nuclear installation discharge stack or underground installation discharge stack) for the package transfer ramp.

The exposure pathways considered, represented in Figure 3.1.1, are as follows:

- external exposure to the plume;
- internal exposure by inhalation of the plume;
- absorption of tritium through the skin (equal to 40% of the effective dose due to inhalation of treated water);
- external exposure to radioactive deposition;
- internal exposure by inhalation due to deposition in suspension;
- ingestion of contaminated food.

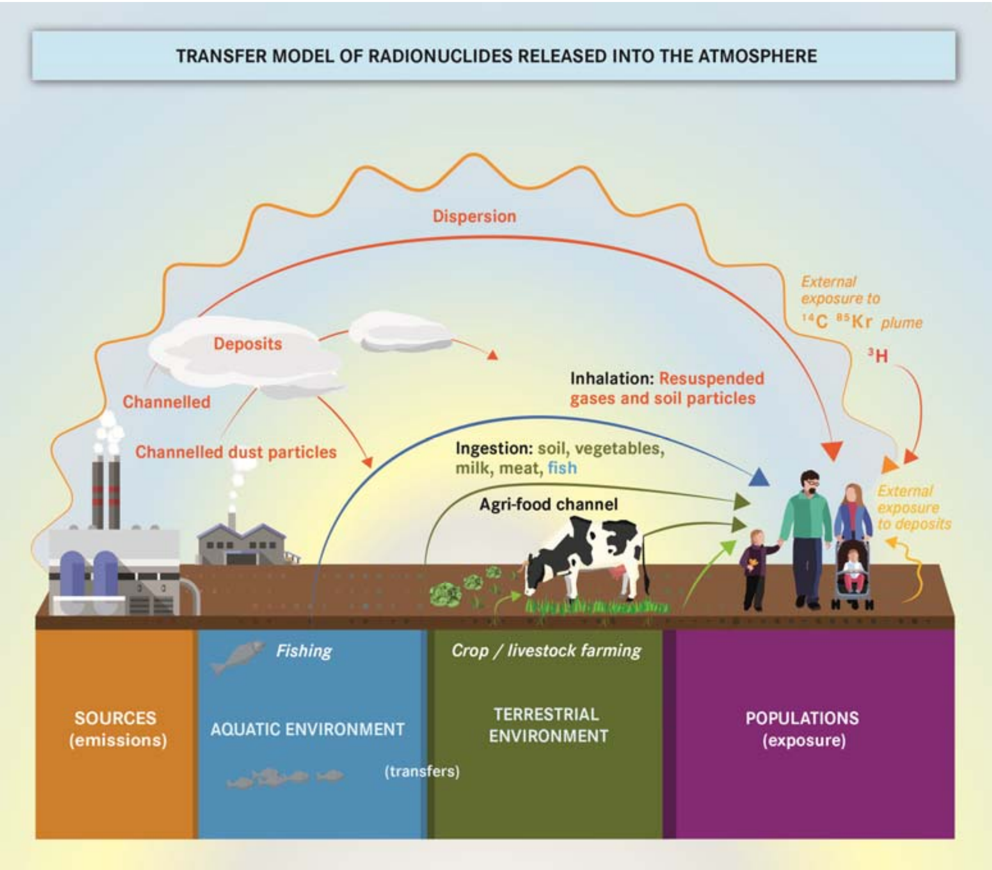

Figure 3.1-1 Diagram of transfer of releases

The pulmonary absorption selected when choosing the inhalation dose coefficients is that recommended in Table 1.3 or, in the absence of any recommendation, the most conservative in the Order of 1 September 2003.

3.1.3.2 Scenario I1 "Two-metre fall of an ET-V or ET-H container being handled on the gantry crane at transhipment from the train or truck to the rail lorry as a result of human error in the train/truck bay"

Description of the scenario and potential consequences

During the transhipment operations, the transport containers are generally positioned horizontally on trains or trucks , that is, on a support frame resting on the container trunnions (ET-V: type A and type B containers) or held directly on the platform of the trailer using a twistlock or equivalent type of system (ET-H: type A and type B containers).

For unloading of road and rail shipments, the containers with trunnions are grasped using heavy lifting beams fitted with a locking system for the trunnions, while the ET-H containers are grasped using rings or lifting points fitted with a locking system. These operations are carried out by operators (attachment and locking of the ends of the lifting system to the container lifting points).

The scenario adopted considers a human error during this unloading operation, involving one of the connection points being incorrectly attached on the transport container, which then falls during transhipment from the train to the rail lorry.

The lifting height of the ET-H containers is about 1.2 m, while that of the trunnion containers is a little higher, about 2 m, as they have to be removed from their racks.

Cigeo is liable to accommodate both types of container as defined by the transport regulations:

- type B containers which constitute most of those received and which are qualified for a drop height of 9 m;
- type A containers, for certain ILW-LL packages with less activity, which have designed-in drop robustness but which are not qualified and for which the containment of radioactive substances cannot be guaranteed.

Following a two-metre fall, the geometries of the container and the packages inside it are retained. The hall is open to the outside and naturally ventilated, so there is no problem with heat and gas removal. Consequently, criticality-safety, control of radiolysis gases and the release of heat from the waste are unaffected.

For a type B container, the design margins adopted (qualification for 9 m fall onto a flat surface), indicate that a type B container with its transport covers constitutes a robust passive barrier and thus rules out all risk of loss of container containment during such an event. Container containment is maintained. No radiological consequences need to be assessed.

Owing to their design, type A containers are not considered robust with a two-metre fall, so containment thus relies on the robustness of the primary packages being transported:

- the primary packages qualified for a two-metre fall inside the container constitute a robust passive barrier. Thus for the type A containers transporting primary packages qualified for a two-metre fall, the risk of loss of containment is excluded and no radiological consequences are to be assessed;
- In the case of containers transporting primary packages not qualified for a two-metre fall, the risk of the dispersion of radioactive substances into the train/truck unloading bay is to be assessed. The radioactive gases and aerosols disperse into the train/truck unloading bay. The hall is equipped with natural ventilation. There is no static or dynamic containment. The potential consequences to be assessed are:
    - ✓ internal exposure of the operators working nearby;
    - ✓ the impact on the environment and the public of radioactive substances being placed in suspension.

Scenario hypotheses

The main hypotheses used are:

- the contamination potential considered is presented in Table 1.6-, Volume II, Section 1.6.3.4; it is estimated on the basis of:
  - ✓ taking into account the packages liable to be transported in a type A container and not qualified for a two-metre fall;
  - ✓ taking into account a particle rate of resuspension in the event of a fall according to the type of waste package (depending on the nature of the container and of the packaged waste);
- the release height (train/truck bay): 0 metres.

Radiological consequences for the public

The maximum short and long-term impact of this scenario is well below 1 mSv.

3.1.3.3 Scenario A6: "Six-metre fall of a primary package unloaded with the bridge crane from an ET-V container following hardware failure of the lifting chain in the unloading cell"

Description of the scenario and potential consequences

The initiating event is a hardware failure of the package lifting system, causing a package in the container to fall into the container. The maximum number of packages affected by this fall is two (one package falling onto another package). The maximum handling height of a package when unloaded in this cell is 6 m, which corresponds to the internal height of an ET-V container docked at the unloading cell, plus the operating margins for package handling.

Following the fall, the container is liable to lose its docking and the cart elevator is liable to collapse.

Control of containment is based on the robustness of the packages and the consequences of the scenario are as follows:

- for the primary packages qualified for a fall of 9 m or more: it is considered that a package qualified for a fall of more than 9 m constitutes a passive barrier that is robust enough to preclude all risk of loss of containment during such an event;
- for the packages qualified for a fall of 6 m: qualification for a fall of more than 6 m (and less than 9 m) is considered to be a passive barrier that is robust enough and no radiological consequences are to be considered. However, the loss of containment by such a package is included in the design-basis scenario for the on-site emergency plan (PUI);
- for the packages not qualified for a fall of 6 m: it is considered that the containment of the packages is compromised, thus creating a suspension of radioactive substances released into the "unloading, inspection and disposal container loading" cell. Assessment of the radiological consequences is required. The results are presented below.

Scenario hypotheses

The main hypotheses used are:

The contamination potential considered is presented in Table 1.6-, Volume II, Section 1.6.3.4; it is estimated on the basis of:

- ✓ consideration of packages not qualified for a fall of 6 m;
- ✓ consideration of a particle suspension ratio in the event of a fall according to the primary package family (depending on the nature of the container and of the packaged waste);

- consideration of two levels of filtration: retention factor 10^{-4};
- height of release (EP1 discharge stack): 17 m.

Radiological consequences for the public

The maximum short and long-term impact of this scenario is well below 1 mSv.

3.1.3.4 Scenario A7 “fire on the cart involving a primary package at the inspection station of the package unloading cell”

Description of the scenario and potential consequences

The cells for receiving packages from the transport container are capable of taking packages at level +6.00 m for the vertical-type containers (ET-V) and level +0.00 m for the horizontally unloaded containers (ET-H).

These cells enable waste package transfer operations to be performed from the unloading zones up to the cells for package inspection and primary package loading into the disposal packages.

The primary packages are unloaded from the container on a table enabling the primary packages to be transferred to the inspection cell, while limiting the handling height.

This cell comprises various equipment with fire loads that would be concerned by a fire: cart, turntable, control robot, etc.

The initiating event is an outbreak of fire on an electrical cubicle of the cart which spreads to the equipment in the inspection station. The on-board extinguishing system on the cart and the automatic ambient fire detection system are not functioning. The intensity of the fire is low. Its duration is limited by the presence of a fixed extinguishing system actuated after detection via the video surveillance system in the control room.

Only the package present in the inspection station is affected.

Management of containment is based on the behaviour of the primary package with a temperature rise dependent on the nature of the container, the waste and its conditioning.

The ventilation in the area is stopped and leaks to the adjacent zones are extracted by the ventilation with a HEPA filtration level.

Scenario hypotheses

The main hypotheses used are:

- The contamination potential considered is presented in Table 1.6-, Volume II, Section 1.6.3.4; it is estimated on the basis of:
  - ✓ conservative mobilisation of 100% of the external surface contamination of the package present at the inspection station and of the gases contained in this package;
  - ✓ taking into account the rate of resuspension in the event of a fire;
- height of release (EP1 discharge stack): 17 metres;
- the release of radioactive substances to the adjacent premises is limited by the walls of the cell: a bounding hypothesis is that 10% of the activity present in the area is dispersed;
- the retention factor of the HEPA filter is 10^{-3}.

Radiological consequences for the public

The maximum short and long-term impact of this scenario is below 1 mSv.

3.1.3.5 Scenario A16 "Fall of an ILW-LL disposal package following failure of the elevator in the handling cell of the ILW-LL disposal cell"

Description of the scenario and potential consequences

On extraction from the cask, the disposal packages are placed on an elevator which raises them to the correct height for collection by the disposal package crane. The handling heights using the elevator depend on the type of cell and are between 1.65 m and 3.3 m. Failure of one of the components of the package lifting chain can lead to the elevator table and the package falling. The fall is an accident situation because it implies the failure of a major prevention barrier (fall prevention guides, failsafe brakes).

A shock-absorber provides package deceleration compatible with a package's ability to withstand a fall of less than 1.2 m.

Containment management is based on the robustness of the primary packages, the scenario consequences then being as follows:

- for the primary packages qualified for a fall of 1.2 m or more: it is considered that a package qualified for a fall of more than 1.2 m constitutes a passive barrier that is robust enough to preclude all risk of loss of containment during such an event;
- for the packages not qualified for a fall of 1.2 m: for a fall of 1.2 m, their containment is compromised. The gases and aerosols are released into the handling cell. This cell constitutes a single air volume with the disposal cell, which comprises a HEPA filtration stage (containment class C2). The consequences are releases of radioactive gases and aerosols to the discharge stack. Assessment of the radiological consequences is required. The results are presented below.

Scenario hypotheses

The main hypotheses used are:

- The contamination potential considered is presented in Table 1.6-, Volume II, Section 1.6.3.4; it is estimated on the basis of:
  - ✓ consideration of packages not qualified for a fall of 1.2 m;
  - ✓ consideration of a particle rate of resuspension in the event of a fall according to the primary package type (depending on the nature of the container and of the packaged waste) presented in Appendix I of Volume III;
- consideration of a retention factor of 10^{-2} owing to the disposal container (see Section 2.1.2 of Volume III);
- release height (VVE discharge stack): 12 m.

Radiological consequences for the public

The maximum short and long-term impact of this scenario is well below 1 mSv.

3.1.3.6 Scenario A17 "Fire on the disposal package crane involving packages in the ILW-LL disposal cell"

Description of the scenario and potential consequences

The disposal package crane takes the package in the handling cell and transfers it to its disposal position in the cell. The only equipment present in the cell is the disposal package crane.

The initiating event is an outbreak of fire in an electrical cubicle on the crane, which spreads to the crane equipment. The on-board extinguishing system on the crane is not functioning. The intensity of the fire is low and of limited duration given the small fire load present.

The number of packages affected by the fire corresponds to the number of packages placed in the width of the cell situated in the vertical axis of the crane (2 or 3 packages depending on the type of cell).

Management of containment is based on the behaviour of the packages with a temperature rise dependent on the nature of the container, the waste and its conditioning and the fire resistance of the disposal containers.

Ventilation in the cell is stopped by closure of the dampers on the cell air supply network. Static containment is guaranteed by the package and the walls of the cell. Any leaks spread to the access drift, which is no longer ventilated. An assessment is carried out, assuming that they are collected by the ventilation in the connecting drifts and discharged by the shaft zone stack which has no HEPA filtration.

Scenario hypotheses

The main hypotheses used are:

- The contamination potential considered is presented in Table 1.6-, Volume II, Section 1.6.3.4; it is estimated on the basis of:
    - ✓ conservative mobilisation of 100% of the surface contamination on the outside of the packages and the gases contained in the packages;
    - ✓ consideration of the suspension levels in the event of a fire;
- release height (VVE discharge stack): 12 metres;
- the release of radioactive substances to the access drift is limited by the wall of the docking cell: a bounding hypothesis is that 10% of the activity present in the cell is dispersed;
- absence of HEPA filtration on the ventilation network of the access and connecting drifts.

Radiological consequences for the public

The maximum short and long-term impact of this scenario is below 1 mSv.

3.1.3.7 Summary of the design-basis scenarios impact assessments

Table 3.1.5 presents the design-basis scenarios impact assessments.

Table 3.1-5Design-basis scenarios impact assessments

No.	Area / zone	Scenario	Maximum short-term impact (mSv)	Maximum long-term impact (mSv)
I1	Train/truck bay	2m fall of an ET-V or ET-H container being handled on the gantry crane at transhipment from the train or truck to the rail lorry as a result of human error	<< 1	<< 1
A6	Unloading cell	6 m fall of a CP unloaded with the bridge crane from an ET-V following hardware failure of the lifting chain	<< 1	<< 1
A7	Unloading cell	Fire on the cart involving a primary package at the inspection station	< 1	< 1
A16	ILW-LL handling cell	Fall of a disposal package following an elevator failure	<< 1	<< 1
A17	ILW-LL disposal cell	Fire on the disposal package crane involving a disposal package	< 1	< 1

3.2 Study of design-basis situations in the on-site emergency plan (PUI)

To verify the robustness of the installations, PUI design-basis situations are identified to ensure that they do not lead to a cliff-edge effect. For some of them, the PUI could be activated.

3.2.1 Presentation of design-basis situations in the on-site emergency plan (PUI)

Situations said to be “PUI design-basis” identified for the surface nuclear installations and the underground installation are presented in Table 3.2- and Table 3.2- respectively.

Table 3.2-1 Design-basis situations in the PUI for surface nuclear installations

No.	Area / zone	Scenario
P1	Process building	Earthquake stronger than the safe shutdown earthquake (SMS)[67]
P2	Receiving area no. 2 for ET-V	Fall < 6 m by an ET-V container without cover being handled on the bridge crane, at tilting into the pit, combined with failure of the shock-absorbing system
P3	Unloading cell	6 m fall of a package unloaded with the bridge crane from a container, following hardware failure of the lifting chain with loss of containment of the packages qualified for a fall less than 9 m
P4		Fire on the cart involving a primary package at the inspection station, combined with failure of extinguishing systems
P5	ILW-LL cask loading cell	1.2 m fall of a disposal package, following hardware failure of the lifting chain with loss of containment of the primary packages qualified for a fall less than 2 m

Table 3.2-2 Design-basis situations in the PUI for the underground installation

No.	Area / zone	Scenario
P6	Operations zone	Earthquake stronger than the SMS
P7	Ramp transfer lower station	Low-speed collision of the ramp transfer system with a cask containing a disposal package at the lower station, combined with failure of the shock-absorbing buffers
P8	ILW-LL handling cell	Fall of a disposal package following an elevator failure, combined with failure of the shock absorber
P9	ILW-LL disposal cell	Fire on the disposal package crane involving a disposal package, combined with failure of a disposal container

[67] Scenarios P1 and P6 will be studied for the APD.

3.2.2 Study of scenarios

3.2.2.1 Scenario P2 "Fall < 6 m by an ET-V container without cover being handled on the bridge crane in the receiving area at tilting into the pit combined with failure of the shock-absorbing system"

Description of the scenario and potential consequences

During the tilting operations, the ET-V container it taken by the bridge crane so that it can be positioned vertically above the pit and then positioned on the cart equipped beforehand with a docking frame. The containers are grasped by means of lifting beams fitted with a locking system.

This scenario considers a failure of the lifting chain or a fault in securing the container, which can lead to it falling from a height of less than 6 m during transhipment from the train or truck to the rail lorry. The design-basis for the installation is a fall of the container without its covers into the pit, thanks to a shock-absorbing system at the bottom of the pit, which performs the function of the covers.

For this scenario, failure of this shock-absorbing system is postulated such that the containment of the container and its packages is liable to be compromised.

Control of containment is based on the robustness of the packages and the consequences of the scenario are as follows:

- for the primary packages qualified for a fall of 6 m or more: it is considered that a package qualified for a fall of more than 6 m constitutes a passive barrier that is robust enough to preclude all risk of loss of containment during such an event;
- for the packages not qualified for a fall of 6 m: it is considered that the packages lose their containment, thus creating a suspension of radioactive substances released into the receiving area. The hall has C1 class nuclear ventilation. Assessment of the radiological consequences is required. The results are presented below.

Scenario hypotheses

The main hypotheses used are:

- The contamination potential considered is presented in Table 1.6-, Volume II, Section 1.6.3.4; it is estimated on the basis of:
  - ✓ consideration of packages not qualified for a fall of 6 m;
  - ✓ consideration of a particle rate of resuspension in the event of a fall according to the primary package family (depending on the nature of the container and of the packaged waste);
- height of release (EP1 discharge stack): 17 m.

Radiological consequences for the public

The maximum long-term impact of this scenario is below 5 mSv.

3.2.2.2 Scenario P3 "Six-metre fall of a primary package unloaded with the bridge crane from a container, following hardware failure of the lifting chain in the container unloading cell with loss of containment of the primary packages qualified for a fall less than 9 m"

This scenario is similar to that presented in Section 3.1.3.3 with an additional compounding factor, that is the loss of containment of all the primary packages not qualified for a 9 m fall.

<u>Scenario hypotheses</u>

The main hypotheses used are:

- The contamination potential considered is presented in Table 1.6-, Volume II, Section 1.6.3.4; it is estimated on the basis of:
  - ✓ consideration of packages not qualified for a fall of 9 m;
  - ✓ consideration of a particle rate of resuspension in the event of a fall according to the primary package type (depending on the nature of the container and of the packaged waste);
- consideration of two levels of filtration: retention factor 10^{-4};
- height of release (EP1 discharge stack): 17 m.

<u>Radiological consequences for the public</u>

The maximum long-term impact of this scenario is well below 1 mSv.

3.2.2.3 Scenario P4 "Fire on the cart involving a primary package at the inspection station of the primary packages unloading cell, combined with failure of the extinguishing system"

<u>Description of the scenario and potential consequences</u>

This scenario is identical to the design-basis scenario presented in Section 3.1.3.4 with the additional failure of the extinguishing system.

Management of containment is based on the robustness of the package to a temperature rise which depends on the nature of the container, the waste and its conditioning.

The intensity of the fire is low but its duration is longer than for the design-basis scenario. Its duration is limited by the presence of a fixed extinguishing system actuated after detection via the video surveillance system in the control room.

The maximum number of packages affected is the package present at the inspection station.

The ventilation in the area is stopped and leaks to the adjacent zones are extracted by the ventilation with a HEPA filtration level.

<u>Scenario hypotheses</u>

The main hypotheses used are:

- mobilisation of 25% of the source term present at the inspection station;
- consideration of the suspension levels in the event of a fire;
- height of release (EP1 discharge stack): 17 metres;
- release of radioactive substances to the adjacent premises is limited by the walls of the cell: a realistic hypothesis is that 1% of the activity present in the area is dispersed;
- the retention factor of the HEPA filter is 10^{-3}.

<u>Radiological consequences for the public</u>

The maximum short and long-term impact of this scenario is below 1 mSv.

3.2.2.4 Scenario P5 "1.2 m fall of a disposal package, following hardware failure of the lifting chain with loss of containment of the primary packages qualified for a fall less than 2 m in the cask loading cell"

Description of the scenario and potential consequences

The failure by one of the components of the disposal packages lifting chain or of the loading table can lead to a package falling during handling. This scenario includes an additional compounding factor, that is the loss of containment of all the primary packages contained in a disposal container, qualified for less than 2 m.

Scenario hypotheses

The main hypotheses used are:

- The contamination potential considered is presented in Table 1.6-, Volume II, Section 1.6.3.4; it is estimated on the basis of:
  - ✓ consideration of packages not qualified for a fall of 2 m;
  - ✓ consideration of a particle suspension ratio in the event of a fall according to the primary package type (depending on the nature of the container and of the packaged waste);
- consideration of a retention factor of 10^{-2} owing to the disposal container;
- consideration of one level of filtration: retention factor 10^{-3};
- height of release (EP1 discharge stack): 17 m.

Radiological consequences for the public

The maximum long-term impact of this scenario is well below 1 mSv.

3.2.2.5 Scenario P7 "Low-speed collision of the ramp transfer system at the lower station, combined with failure of the shock-absorbing buffers"

Description of the scenario and potential consequences

This scenario corresponds to failure of the ramp transfer system to stop at the lower station at low speed, owing to failure of the control or braking system, combined with an additional compounding factor that is failure of the buffers at the end of the rails. It is assumed that these latter fail to perform their shock-absorbing function. Given the design of the ramp transfer system, the energy associated with the resulting collision speed corresponds to an energy equivalent to that of a package falling 1.2 m. In addition, the cask no longer performs its containment role. The consequences of this scenario depend on the robustness of the primary packages to a fall of 1.2 m.

Scenario hypotheses

The main hypotheses used are:

- The contamination potential considered is presented in Table 1.6-, Volume II, Section 1.6.3.4; it is estimated on the basis of:
  - ✓ consideration of packages not qualified for a fall of 1.2 m;
  - ✓ consideration of a particle suspension ratio in the event of a fall according to the primary package type (depending on the nature of the container and of the packaged waste);
- consideration of a retention factor of 10^{-2} owing to the disposal container;
- absence of filtration;
- height of release (EP1 discharge stack): 17 m.

Radiological consequences for the public

The maximum long-term impact of this scenario is well below 1 mSv.

3.2.2.6 Scenario P8 "Fall of a disposal package following an elevator failure, combined with failure of the shock-absorber in the ILW-LL handling cell"

Description of the scenario and potential consequences

This scenario is identical to the design-basis scenario presented in Section 3.1.3.5 with the additional failure of the shock-absorber, which no longer performs its role. of containment relies on the robustness of the primary packages to a fall which can be up to 3.3 m, depending on the type of cell. The consequences of the scenario are therefore as follows:

- for the primary packages qualified for a fall of 3.3 m or more: it is considered that a package qualified for a fall of more than 3.3 m constitutes a passive barrier that is robust enough to preclude all risk of loss of containment during such an event;
- for the primary packages not qualified for a fall of 3.3 m: for the packages not qualified for a fall of 3.3 m, their containment is compromised. The gases and aerosols are released into the handling cell. This cell constitutes a single air volume with the disposal cell, which comprises a HEPA filtration stage (containment class C2). The consequences are releases of radioactive gases and aerosols to the discharge stack. Assessment of the radiological consequences is required. The results are presented below.

Scenario hypotheses

The main hypotheses used are:

- The contamination potential considered is presented in Table 1.6-, Volume II, Section 1.6.3.4; it is estimated on the basis of:
  - ✓ consideration of packages not qualified for a fall of 3.3 m;
  - ✓ consideration of a particle rate of resuspension in the event of a fall according to the primary package type (depending on the nature of the container and of the packaged waste);
- the ILW-LL disposal container is not designed for a fall of 3.3 m, it is assumed that it is no longer able to retain particles which are returned to suspension;
- release height (VVE discharge stack): 12 m.

Radiological consequences for the public

The maximum long-term impact of this scenario is well below 1 mSv.

3.2.2.7 Scenario P9 "Fire on the disposal package crane involving packages in the ILW-LL disposal cell, combined with failure of the disposal container"

Description of the scenario and potential consequences

This scenario is identical to the design-basis scenario presented in section 3.1.3.6 with the additional failure of the disposal container (even though fire-qualified).

Control of containment is based on the temperature rise behaviour of the packages present in the faulty disposal container, which depends on the nature of the primary container, the waste and its conditioning and the fire resistance of the disposal container.

Ventilation in the cell is stopped by closure of the dampers on the cell air supply network. Static containment is guaranteed by the package and the walls of the cell. Any leaks spread to the access drift, which is no longer ventilated. An assessment is carried out, assuming that they are collected by the ventilation in the connecting drifts and discharged by the shaft zone stack which has no HEPA filtration.

<u>Scenario hypotheses</u>

The main hypotheses used are:

- mobilisation of 25% of the source term present in the disposal package;
- consideration of the resuspension levels in the event of a fire;
- release height (VVE discharge stack): 12 metres;
- the release of radioactive substances to the access drift is limited by the walls of the cell and the handling cell: a realistic hypothesis is that 1% of the activity present in the cell is dispersed;
- the absence of HEPA filtration on the ventilation network of the access and connecting drifts.

<u>Radiological consequences for the public</u>

The maximum long-term impact of this scenario is below 10 mSv.

3.2.2.8 Summary of the PUI design-basis scenarios impact assessments

Table 3.2- - below presents the PUI design-basis scenarios impact assessments.

Table 3.2-3 PUI design-basis scenarios impact assessments

No.	Area / zone	Scenario	Maximum long-term impact *(mSv)*
P2	Receiving area no. 2 for ET-V	6 m fall of an ET-V container without cover being handled with the bridge crane, at tilting into the pit, combined with failure of the shock-absorbing system	<5
P3	Unloading cell	6 m fall of a primary package unloaded with the bridge crane from an ET, following hardware failure of the lifting chain with loss of containment of the CPs qualified for a fall less than 9 m	<<1
P4		Fire on the cart involving a primary package at the inspection station, combined with failure of extinguishing systems	<1
P5	ILW-LL cask loading cell	1.2 m fall of a disposal package, following hardware failure of the lifting chain with loss of containment of the CPs qualified for a fall less than 2m	<<1
P7	Ramp transfer system lower station	Low-speed collision at the ramp transfer system lower station combined with failure of the shock-absorbing buffers	<<1
P8	ILW-LL handling cell	Fall of a disposal package following an elevator failure, combined with failure of the shock-absorber	<<1
P9	ILW-LL disposal cell	Fire on the disposal package crane involving a disposal package, combined with failure of a disposal container	<10

3.3 Presentation of precluded situations

This chapter presents the situations ruled out at the basic engineering design (APS). These are accident situations for which a large number of preventive measures of proven robustness are combined (situation that is extremely improbable with a high degree of confidence or physically impossible situations).

Table 3.3-1 Main precluded situations

Area / zone	Scenario	Main preventive measures
Train/truck unloading bay	Loss of containment of the packages present in a transport container in the event of a fire in the shunter or the truck	Container qualification with transport regulations Fixed extinguishing system Intervention by the site emergency response teams
Receiving area no. 3 for horizontally unloaded transport containers	Loss of containment of the packages present in a shipment container in the event of a fire in the lorry	Protection provided by the transport container Fixed extinguishing system Intervention by the site emergency response teams
Unloading, inspection and disposal container loading cell	Fire on the bridge crane following a spread of flaming oil from the reduction gears on the ET unloading station or at the disposal container loading station, with damage to the packages	Physically impossible owing to the design of the bridge crane
Exhaust air extraction shaft	Fire in the shaft	No fire loads
Surface premises	LEL reached owing to loss of nuclear ventilation	Primary packages hydrogen production limits, Ventilation system Significant dilution volume in the premises Physically impossible (time to reach LEL > 6 months)
	Loss of control of heat releases	Primary packages thermal power limits Physically impossible
	Criticality accident in a “Criticality Unit” of the cells	Fissile material mass limits per package No significant deformation of the packages in the abnormal configurations
	Significant irradiation of the personnel when entering the cells	Redundant access locking systems

Area / zone	Scenario	Main preventive measures
Ramp transfer system upper or lower station	Collision/fall of surface shuttle or underground cart without the presence of the ramp transfer system	Design of the ramp transfer system: interlocking between tracks power supply and shuttle or cart presence detection making it impossible for the shuttle to approach if the ramp transfer system is absent
Ramp transfer system lower station	Runaway by ramp transfer system without tripping of all the braking systems, leading to high-speed collision at the lower station	Cable design Independent, redundant braking systems Redundant control system
Cask handling – surface and underground installations	Tipping/fall of a cask transported on a vehicle (shuttles, funicular, cart)	Physically impossible for a cask to tip in the ramp (dimensions of the ramp/dimensions of cask + ramp transfer system) Redundant cask locking on the ramp transfer system (4 feet)
	LEL reached in the cask following stoppage of cask handling process leading to its immobilisation	Primary packages hydrogen production limits Design of transfer machinery Cask sweeping orifices
ILW-LL disposal cell	LEL reached owing to loss of nuclear ventilation	Primary packages hydrogen production limits Ventilation design + mobile fans
	Loss of control of heat releases	Primary packages thermal power limits Physically impossible
	Acute irradiation of the personnel when entering the cells	Redundant access locking systems
	Criticality accident in a “Criticality Unit” of the ILW-LL cells	Fissile material mass limits per package No significant deformation of the packages in the abnormal configurations
	Loss of containment of a large number of ILW-LL disposal packages emplaced in the cell before the end of operation	Design of ILW-LL disposal packages
	Uncontrolled fire in the cell, leading to a disposal package catching fire and the fire spreading to the adjacent packages	Limitation of fire load Fire qualification of disposal containers Fire test programme

Area / zone	Scenario	Main preventive measures
Handling cell	Uncontrolled fire in the handling cell involving a disposal package	Redundant detection and extinguishing systems
Surface and underground installations	Loss of containment of one or more HLW disposal packages during handling operations in the disposal cell before the end of operations	Design of HLW disposal packages

The elements allowing the preclusion of these scenarios are:

- the availability and effectiveness of the ventilation system in the ILW-LL packages buffer zones on the surface (dynamic and static containment) and of the ILW-LL disposal cells and, through this, the reliability of the electrical power supply and the control system;
- the availability and effectiveness of the transfer means for the ILW-LL packages from surface loading to underground unloading and, through this, their electrical power supply and control system;
- the availability and effectiveness of the systems for access to the cells on the surface or to the ILW-LL handling cells underground;
- the availability and effectiveness of the systems contributing to maintaining the geometry of the packages (no tipping, no missile effect from the equipment present, etc.).

The availability and effectiveness of the ventilation systems requires a design basis taking into account failures (redundancy of extractors, of their electrical power supply and control system), internal hazards (segregation of ventilation equipment, their power supply and control system) and external hazards (seismic design, installation indoors to protect them from external hazards). In addition, extra measures mitigate the total loss of ventilation, with installation of back-up ventilation for the ILW-LL cells considered to be critical in terms of radiolysis.

The availability and effectiveness of the package transfer means, requires a design basis taking into account failures (redundancy of transfer means, redundancy of electrical power supplies and control systems, availability of back-up transfer means), internal hazards (design sizing of transfer means, segregation of electrical power supplies and control systems) and external hazards (seismic design, installation indoors protecting them from external hazards).

The availability and effectiveness of the systems for access to the cells and ILW-LL cells also a involves design basis taking into account failures (redundancy of systems, of their electrical power supply and control systems), internal hazards (equipment design sizing, segregation of electrical power supplies and control systems) and external hazards (seismic design, installation indoors in premises protecting them from external hazards).

The availability and effectiveness of systems contributing to maintaining the geometry of the packages primarily involves the design of the support structures and equipment present in order to rule out all missile effects, in particular with regard to the seismic hazard.

4

Accident / post-accident situations management

This chapter presents the principles and the measures taken for management of accident situations. The PUI design-basis accident situations are highlighted.

Additional data will be provided in the PUI design-basis study which will be transmitted with the DAC.

4.1 Design-basis accident situations

4.1.1 Review of the situations

The various design-basis situations identified through the assessment of the various hazards (see chapter 3) are:

- fall of a transport container in the train/truck unloading bay and the transport container receiving area;
- fire on a truck in the train/truck bay or in the transport container receiving area;
- fall of a primary or disposal package in the surface installation areas;
- fire on a package transfer cart;
- fire on a cart transporting a cask;
- collision of a cask;
- fire on an equipment item or on the disposal package crane involving a disposal package in the handling cell or in the cell;
- fall of a disposal package in the handling cell.

4.1.2 Principles adopted

For each of the accident situations identified, the design proposed enables them to be controlled, with the installation kept in a safe state following the envisaged situation. Operation resumes after remedial maintenance or after specific measures have been taken.

The principles adopted for the various fall and collision situations in the various areas of the installation, considered to be accident situations, are:

- fall of a transport container:
  - ✓ the container is immobilised on the ground;
  - ✓ the concrete slab in the hall is locally damaged;
  - ✓ the containers can still be handled;
- fall of a package at unloading from the transport container:
  - ✓ the primary packages are in the container, itself situated in the docking cell;
  - ✓ the primary packages can still be handled with the available equipment and a few specific equipment items if necessary. The relevance of this specific equipment will be examined between now and commissioning of Cigeo in the light of the more detailed analysis of the situation and of the hypotheses to be adopted;
- fall of a primary package when being placed in a disposal container:
  - ✓ the primary packages are located in the container loading cell;
  - ✓ as the drop height is limited, they can still be handled with the available equipment;
- fall or collision by a disposal package:
  - ✓ the package is immobilised in the cask loading cell, handling cell or disposal cell68;
  - ✓ the package can still be handled after a fall of about 1.20 m (maximum drop height at this stage of the design) which is less than the 2.3 m drop resistant height of the disposal packages, using the equipment present, plus possible systems appropriate for its recovery which will need to be designed between now and Cigeo commissioning;
  - ✓ the package can be recovered after modification of its location on the stack of packages in the cell, for example following a collision. Specific equipment can take the place of the equipment

[68] The collision of a disposal package in the cell is envisaged in the chapter dealing with the handling risk. It has no radiological consequences.

present on the disposal package crane, and it is capable of automatically identifying the position of the package so that it can be repositioned for recovery. For the basic engineering design (APS), a test bench was used to perform several test cycles covering a package rotation of about ten degrees and a translation of about twenty centimetres. The APS completion hypotheses will be consolidated during the APD to determine the bounding situation to be considered for the package recovery equipment.

With regard to the design-basis fire accident situations, the measures adopted enable the fire to be controlled in the various areas of the installation:

- fire in the train/truck bay:
  - ✓ the hall structures are robust to a conventional ISO fire;
  - ✓ the fire is controlled by the emergency response services;
  - ✓ the container can still be handled after the fire;
- fire in the primary packages inspection station:
  - ✓ the preventive measures mitigate the intensity and duration of the fire;
  - ✓ the degradation of the package due to the fire is thus limited;
  - ✓ the package is immobilised in the inspection station. The equipment is no longer functional.
  - ✓ the fire remains confined to the cell and does not spread to the areas before and after it;
  - ✓ the available equipment in the cell, such as the crane or a new transfer cart for example, can be used to recover the required package and transfer it to a holding zone;
- fire during package transfer:
  - ✓ the preventive measures mitigate the intensity and duration of the fire;
  - ✓ the transfer vehicle is immobilised in the ramp or in a drift;
  - ✓ the fire is rapidly brought under control by the emergency response services;
  - ✓ the casks are robust to a conventional ISO fire lasting two hours: the feet and frames of the casks are strong enough to prevent the cask from tipping over and thus enable it to be handled post-accident. For the same reason, the carrier structures of the transfer vehicles, (shuttle, MLL, turntable) have the same degree of strength;
  - ✓ after analysis of the condition of the structures and equipment, the cask can be transferred with a similar vehicle that was not involved in the fire, for return to the surface installations for additional examination or continuation of transfer to the cells;
- fire in the ILW-LL handling cell:
  - ✓ the measures in place allow rapid detection and extinguishing;
  - ✓ the fire is rapidly brought under control by the fixed systems present in the cell, with intervention by the emergency response services also being possible via the access drift;
  - ✓ the disposal packages are robust to the reference fire (no significant alteration of geometry, in particular for grasping), the package involved is immobilised in the handling cell with no dispersion of radioactive substances;
  - ✓ certain equipment in the cell may no longer be functional: the disposal package crane, the radiation protection door, etc.;
  - ✓ the fire remains confined to the cell and does not spread to the access drift via the docking facade, nor to the cell via the radiation protection door. The docking facade in fact acts as a fire sector and, when closed, the radiation protection door constitutes a thermal shield between the handling cell and the usable part of the cell;
  - ✓ after analysis of the condition of the structures, equipment and the package, the decision to continue the process to transfer the package to the cell or remove it and return it to the surface is made with the possible adoption of compensatory measures such as surveillance (fire, contamination) and nuclear ventilation in the cell, reinforced monitoring of transfer of the package in question from the cell to the surface installation, etc.
- fire in a disposal cell:
  - ✓ the preventive measures mitigate the intensity and duration of the fire;
  - ✓ the fire does not cause the disposal package crane nor the structures to collapse;

- ✓ the disposal packages are robust to the reference fire, the package involved is positioned by the disposal package crane and immobilised in the cell, with no dispersion of radioactive substances;
- ✓ the disposal package crane is no longer functional; measures enable it to be returned to the handling cell for remedial maintenance or equipment replacement, so that the packages involved in the fire can be collected.

4.2 PUI design-basis accident situations

4.2.1 Review of the situations

The various PUI design-basis situations identified by the assessment of the various hazards are:

- the occurrence of an earthquake stronger than the SMS on the process building or the operation zone of the underground installation;
- airplane crash with a fire not rapidly brought under control;
- fall of the transport container without cover when being tilted into the pit, combined with failure of the shock-absorbing system;
- fall of a primary package in the unloading cell, with loss of containment of packages qualified for a drop height of less than 9 m;
- fall of a disposal package in the cask loading cell, with loss of containment of packages qualified for a drop height of less than 2 m;
- fire on the cart involving a primary package at the inspection station in the unloading cell, with failure of the extinguishing system;
- low-speed collision of the ramp transfer system at the lower station, combined with failure of the shock-absorbing buffers;
- fall of a disposal package in the handling cell, combined with failure of the shock-absorber.
- fire on the disposal package crane involving a disposal package in the cell, with failure of a disposal container.

4.2.2 Principles adopted

For each of the PUI design basis accident situations, the measures proposed enable them to be controlled, with the installation kept in a safe state following the envisaged situation. The analysis of the post-accident condition of the installation then enables a decision to be reached on the preconditions for resumption of operations and whether or not the package can be removed. Various situations linked to the condition of the package and to the capacity of the Cigeo equipment are then possible:

- the primary or disposal package can be recovered with the means available in Cigeo;
- the primary or disposal package requires specific measures to allow its recovery, for example after fixing of the contamination, change to or adaptation of the handling equipment, provision of handling equipment or transfer cask specific to the post-accident situation;
- the disposal package and/or its environment do not enable its recovery to be envisaged in sufficient conditions of safety; the possibility of leaving it as-is in the disposal cell should be analysed in the light of safety requirements in operations and after closure, and of the recoverability conditions.

In the case of an earthquake, operation of the installation is stopped, although the safety functions are not compromised. Resumption of operations is subject at least to an inventory of the installation (patrol, inspection, etc.) in particular to verify the correct operation (tests, etc.) of the elements important for protection (EIP) and the absence of significant damage to the civil engineering of the premises and structures, the transfer and handling equipment runways and of the packages in the disposal cell.

With regard to an airplane crash on the process building, design measures ensure that the external concrete slabs and walls are able to withstand an airplane crash. The safety targets are not reached. Intervention by the emergency services is required to put out the fire following an airplane crash. The resumption of operations depends on the post-accident condition of the building.

For crash/collision and fire situations, the principles adopted for post-accident management of design-basis accident situations can be transposed.

For these situations, the PUI can be activated. A PUI design-basis study will be provided with the preliminary safety analysis report for the DAC. This study will cover the accidents mentioned, which require protection measures on the site or outside the site, or which are such as to affect the interests mentioned in I of Article 28 of the Act of 13 June 2006. It will describe the various accident scenarios and their consequences for the safety of the installations and the protection of individuals and will present the organisation adopted by the licensee for its own emergency response means to mitigate the effects of an incident.

At this stage, the decision to activate the on-site emergency plan (PUI) lies with the manager or his representative, following a rapid analysis of the situation.

The PUI activation criteria concern:

- for the conventional PUI, the severity of the injuries and the number of victims;
- for the radiological PUI or linked to hazardous products:
  - ✓ the situations identified in advance, for example:
    - in the event of an airplane crash on the installation;
    - in the event of an earthquake,
    - for all other predetermined PUI design-basis scenarios;
  - ✓ radiological criteria or hazardous product involvement criteria, for example exceeding the radioactivity thresholds at the exit from the stacks.

With regard to the licensee’s organisation, Andra determines two levels of mobilisation for management of an emergency situation:

- a central level under the responsibility of the general management;
- a local level under the responsibility of the management of the centre concerned.

An emergency unit is set up and is proportionate to the gravity of the envisaged situations. If the PUI is activated, an emergency management room is made available to the local management command centre (PCDL) team (also called the emergency response team), assisted by experts if necessary.

All the documentation essential for emergency management is available in this room. Computerised supervision also enables the emergency team to consult the condition of the functions and safety parameters as necessary. This HMI is in consultation mode only, with the nuclear processes only being controllable from the centralised control room (SCC) or from the local command posts if the SCC is unavailable. The resources of the emergency unit are specified in the emergency management rooms guideline notice (40):

- the human resources and in particular the composition and role of the PCDL, which is also assisted by an emergency management structure at Andra headquarters;
- the planned means of communication (secure communications with the office of the prefect, ASN, IRSN, senior defence and security official, etc., links on and off the site, cameras, radio frequency networks, etc.) along with the necessary utilities (ventilation, water supply);

- the other hardware resources equivalent to the response resources normally present in a BNI:
  - ✓ fire engine and first-aid response type vehicles;
  - ✓ specialised equipment for personnel decontamination, care for victims, clearance equipment, electricity generator, etc.;
- the PCDL's ability to withstand hazards:
  - ✓ earthquake;
  - ✓ radiological release from Cigeo;
  - ✓ fire;
  - ✓ meteorological events;
  - ✓ intrusions and malicious acts;
- protection of the PCDL in all emergency situations:
  - ✓ remain operational;
  - ✓ supplied with electricity (back-up generator, uninterruptible power supply, etc.);
  - ✓ availability of radiological monitoring;
  - ✓ availability of a filtered air supply;
  - ✓ A guaranteed connection with the outside world.

5

Integration of complementary safety assessments or stress tests

5.1 Principles

The purpose of the stress tests is to assess the robustness of the installation in the light of the events which occurred at Fukushima, that is extreme natural phenomena compromising the safety of the installations. The aim is to assess the behaviour of the installations in these situations, in order to gauge their robustness and the pertinence of the measures planned to deal with an accident, and if necessary to identify additional measures to be taken, both technical and organisational.

Generally speaking, nuclear installations are designed with considerable margins, in order to deal with unusual external phenomena or hardware or human failures. Thus, for the seismic risk, the installations are already designed to withstand a safe shutdown earthquake that is significantly stronger than the strongest earthquake identified in the history of the region in which the installations are located.

The situations examined for the stress tests are the result of the following extreme events or hazards:

- an earthquake stronger than the safe shutdown earthquake;
- flooding greater than the maximum design flood level;
- other extreme natural phenomena (including flooding caused by the safe shutdown earthquake);
- postulated loss of on-site and off-site electrical power supplies;
- postulated losses of cooling systems;
- combination of these two losses;
- operational management of accidents in these extreme situations.

In extreme situations, the stress tests require that the combined failure of a certain number of equipment items be considered, even those in place on the installations designed to deal with the event. The aim is to identify a possible cliff-edge effect and assess the margins with respect to this possible cliff-edge effect, without setting any preconceived limits on the characterisation of the event or hazard.

A cliff-edge effect is a significant discontinuity in the behaviour of the installation, leading to a considerable worsening of the situation, in particular in terms of the quantities of radioactive or hazardous products mobilised.

The risks of appearance of cliff-edge effects, identified below, require the following conditions simultaneously:

- they occur during the situations examined in this document, that is during an earthquake and/or a flood more severe than those considered in the design of the installation, or during postulated losses of electrical power supplies and/or heat sinks;
- they lead to significant environmental consequences greater than those of the events considered in the baseline safety requirements of the installations, including the PUI.

The aim is therefore to identify the cliff-edge effects which, concerning the hazards considered and the losses postulated (loss of electrical power supplies, loss of heat sink and a combination of the two losses), could occur as a result of situations leading to:

- a loss of containment of radioactive or hazardous substances;
- a loss of means of controlling the risk of a hydrogen-related explosion;
- a loss of means of controlling the risk of overheating;

On the basis of the risk assessments and the safety assessments, the following are identified:

- the radioactive or hazardous substances liable to be mobilised and which could lead to a cliff-edge effect;
- the events involving these substances;
- the target safe state and the equipment needed to reach it and maintain it.

This examination is a means of identifying the preventive measures and the existing essential equipment for dealing with these cliff-edge effects.

When dealing with new installations that have not yet been built, the stress test is carried out in parallel with the design studies.

5.2 Identification of feared situations

5.2.1 Identification of substances that can be mobilised

The first step in identifying the feared situations is to produce an inventory of the radioactive and chemical substances present in the installations and which, if dispersed, could have consequences for the interests mentioned in Article L 593-1 of the Environment Code.

5.2.1.1 Radioactive or hazardous substances that can be mobilised

The radioactive substances that are considered to be mobilisable and are present in the installations and which could have consequences in the event of dispersion are primarily those from the waste packages identified. This mobilisation is however only made possible via the degradation of the primary packages or the disposal packages.

The cliff-edge effect identified consists in the sudden degradation of one or more primary or disposal packages leading to a significant release of radioactivity into the environment.

Radioactive substances are also potentially present in the dubious liquid effluents collected in the installations or on certain HEPA filters. Given the activities involved, these substances are considered to be not liable to lead to a cliff-edge effect and are not therefore dealt with in the rest of this document.

5.2.1.2 Chemical or toxic products

Chemical or toxic products are used in small quantities for maintenance operations or for possible operations to ensure radiological cleanness. Their dispersion will have a highly limited health impact and is not therefore covered in the rest of the study. The chemical or toxic products present in the installations do not therefore lead to the identification of any cliff-edge effects.

5.2.2 Feared situations and risks of cliff-edge effect

The situations are identified on the basis of:

- the result of the risks assessment, by looking for the equipment and source terms liable to be affected or mobilised;
- an examination of the accident situations, penalising the hypotheses considered for the hazards examined, in order to look for cliff-edge effects.

Cliff-edge effects are identified by integrating the potential effects of the hazards to be examined into the specifications for the stress tests prescribed by ASN. These hazards are earthquake, flooding (as well as flooding resulting from an earthquake), extreme natural phenomena linked to flooding and loss of electric power.

First of all, the aim is to identify any situations which could lead to a “cliff-edge effect”, without any preconceived limitation on the characterisation (intensity) of the event or hazard. hen entails characterising the potential feared situations previously identified, in order to ensure that they are plausible, then assessing the consequences of these situations in order to determine whether they lead to a cliff-edge effect.

The risks linked to significant releases into the soils, leading to significant contamination of the groundwater table, are also considered to be situations which could lead to a cliff-edge effect.

At this stage in the studies, the potential feared situations liable to lead to a cliff-edge effect with respect to atmospheric releases are:

- the fall of a primary package in the primary packages unloading cell and the loss of the second containment system following an earthquake of an intensity far greater than the SMS;
- the fall of an ILW-LL disposal package in the unloading cell and the loss of the second containment system following an earthquake of an intensity far greater than the SMS;
- a fire in the inspection station of the primary packages unloading cell and the loss of the second containment system following an earthquake of an intensity far greater than the SMS;
- a fire on the disposal package crane in the ILW-LL disposal cell and the loss of the second containment system following an earthquake of an intensity far greater than the SMS;
- the loss of ventilation of the ILW-LL disposal cells liable to lead to the lower explosive limit being reached in the cell following an earthquake of intensity far greater than the SMS or very long duration loss of electric power.

With regard to the situation involving the fall of a primary package in the primary packages unloading cell and the loss of the second containment system following an earthquake of intensity far greater than the SMS, it is assumed that the earthquake leads to failure of the package handling equipment leading to a package falling onto another package during unloading from the transport container (see scenario presented in Section 3.1.3.3) compounded by the failure of the ventilation in the unloading cell. The equipment essential for managing this situation is the static containment provided by the room.

With regard to the situation involving a fall of an ILW-LL disposal package in the handling cell and the loss of the second containment system following an earthquake of intensity far greater than the SMS, it is assumed that the earthquake leads to failure of the package handling equipment leading to the disposal package falling (see scenario presented in Section 3.1.3.5 compounded by the failure of the ventilation in the cell.

The two feared fall situations require static containment to be maintained in order to mitigate the corresponding potential radiological consequences.

With regard to the fire situation at the inspection station of the primary packages unloading cell and the loss of the second containment system following an earthquake of intensity far greater than the SMS, it is assumed that the earthquake causes fire to break out in the equipment of the cell, with failure of the dynamic ventilation (including the last filtration stage). The equipment essential for managing this situation is the static containment performed by the cell: walls, window, doors and fire dampers.

With regard to the situation of a fire on the disposal package crane in the ILW-LL disposal cell and the loss of the second containment system following an earthquake of an intensity far greater than the SMS, it is assumed that the earthquake leads to an outbreak of fire on the disposal package crane and failure of ventilation in the cell. The equipment essential for managing this situation is the static containment provided by the handling cell and the cell: docking facade, doors and fire dampers.

The two feared fire situations require static containment to be maintained in order to mitigate the potential radiological consequences associated with the fire.

With regard to the situation involving loss of ventilation in the ILW-LL disposal cells, liable to lead to the LEL being reached in the cell following an earthquake of greater intensity than the SMS, or long-duration loss of electrical power, in the event of prolonged loss of ventilation in the ILW-LL disposal cells (more than 45 days), the hydrogen LEL is reached and there is then a risk of explosion liable to damage the disposal packages. However, given the times available, remedial measures to restore the ventilation in the cells could be taken. These remedial measures, which will be specified by the time of the DAC, will be essential equipment and protected accordingly.

5.3 Measures adopted

The target is an installations state characterised by limited dissemination of radioactive substances into the environment:

- Concerning a fire or fall following an earthquake of greater intensity than the SMS: control of this state entails sizing of the civil engineering of the primary packages unloading cell and the disposal cells to ensure their mechanical stability and a leak rate appropriate for the feared situations. During the APD, the available design sizing margins will be identified for a stress tests type earthquake in order to decide on whether additional design work is required;
- Concerning the occurrence of an explosion in the ILW-LL cells resulting from the consequences of an earthquake of greater intensity than the SMS, or a long-duration loss of electrical power, control of this state entails:
    - ✓ civil engineering design of the exhaust air extraction shaft (and associated surface structures), of the connecting and ILW-LL access drifts, the handling cells, the ILW-LL disposal cells, the air return drifts, to ensure their stability and rule out creating a potential hazard through the obstruction of renewal air circulation in the cells;
    - ✓ the presence of spares in the installation enabling electrical power to be restored and extraction ventilation to be restarted within a time-frame shorter than the time taken for the LEL to be potentially reached within an ILW-LL disposal cell;
    - ✓ the presence in the installation of ultimate backup mobile electrical power means and the deployment on the site of trained response crews able to utilise the emergency means within a time-frame shorter than the time taken for the LEL to be potentially reached in an ILW-LL disposal cell;
    - ✓ incorporation of the stress test type emergency management measures into the PUI.

6

Elements important for protection (associated requirements and activities)

For the basic engineering design (APS), an initial list of EIP and associated requirements is drawn up for management of the safety functions (see Table 5.3-). Additional EIP are also defined with regard to management of risks (see Table 5.3-).

At this stage, the EIP identified are generic and will be specified in subsequent studies, along with the requirements, which will have to be adapted to the risks.

For the purposes of drafting the detailed design and the continued safety studies, this list is therefore liable to change between now and the DAC.

Table 5.3-1 List of EIP and associated requirements, prepared at the APS stage

Safety function(s)	EIP	Requirement defined for the EIP
All	HLW primary package	Compliance with requirements set in the package acceptance specifications (surface contamination, dose rate, geometry, fall qualification height, etc.)
All	ILW-LL primary package	Compliance with requirements set in the acceptance specifications (surface contamination, dose rate, geometry, production of hydrogen, contamination potential in the event of a fall, etc.) Containment maintained in normal situation during operations for disposal solutions 1 and 3
Containment of radioactive substances	HLW disposal container	Containment maintained in normal and accident (fall, fire) situation during operations
Containment of radioactive substances Evacuation of radiolysis gases	ILW-LL disposal container	Fire performance Limitation of dispersion of radioactive substances in the event of a 2.3 m fall (retention factor 10^{-2}) Containment maintained in normal situation during operation for disposal solutions 2 Evacuation of gases emitted by the primary packages
Containment of radioactive substances	Type B transport container	Compliance with transport regulations
Protection from external and internal exposure Containment of radioactive substances	Certain infrastructures of the surface installation in which radioactive sources are present or through which they pass: civil engineering, openings, cask docking facades Equipment taking part in static containment: windows, penetrations, nuclear ventilation systems containment valves	Containment requirements maintained (leak rate) in normal, earthquake and fire conditions Effectiveness of radiological protection (thicknesses, materials, compliance with dose rate) Design for internal and external hazards: collision, fire, earthquake, snowfall, EF3 tornado, airplane crash (external walls and slabs) Fire performance Existence of a containment space above the premises with operations on primary packages[69]

[69] At this stage, this concerns the “Inspection C5 and Unloading of containers” cell

<table>
<tr><th>Safety function(s)</th><th colspan="2">EIP</th><th>Requirement defined for the EIP</th></tr>
<tr><td>Protection from external and internal exposure
Containment of radioactive substances</td><td colspan="2">Certain infrastructures of the underground installation in which radioactive sources are present or through which they pass: civil engineering, openings, docking facades
Equipment taking part in static containment: penetrations, check valves</td><td>Containment requirements maintained (leak rate) in normal, earthquake and fire conditions
Effectiveness of radiological protection (thicknesses, materials, compliance with dose rate)
Design for internal and external hazards: collisions, fire, earthquake
Fire performance</td></tr>
<tr><td>Protection from external and internal exposure</td><td colspan="2">Equipment taking part in radiological protection: radiation protection doors, operating plug and HLW cells closure plug</td><td>Effectiveness of radiological protection (thicknesses, materials)
Design for internal and external hazards: collisions, fire, earthquake
Fire performance</td></tr>
<tr><td>Protection from external and internal exposure</td><td colspan="2">Closure and locking equipment for premises classified as limited stay areas (orange) and prohibited areas (red)</td><td>Maintained closure, locking and operating status in the event of earthquake, fire, collisions, loss of utilities, etc.</td></tr>
<tr><td>Containment of radioactive substances</td><td colspan="2">ILW-LL cask docking system</td><td>Containment requirements maintained (leak rate) in normal, earthquake and fire conditions
Design for internal and external hazards: collisions, fire, earthquake
Fire performance</td></tr>
<tr><td>Protection from external and internal exposure</td><td colspan="2">HLW casks docking/interlocking system</td><td>Effectiveness of radiological protection (compliance with dose rate)
No closure of doors
No movement of the cask</td></tr>
<tr><td>Evacuation of the residual thermal power from waste</td><td colspan="2">HLW cell design</td><td>Compliance with inter-axial distance between cells</td></tr>
<tr><td rowspan="2">Protection from external and internal exposure
Containment of radioactive substances</td><td rowspan="4">ILW-LL casks</td><td>Containment and shielding</td><td>Containment requirements maintained (leak rate) in normal, earthquake and fire conditions
Effectiveness of radiological protection (compliance with dose rate)
Design for internal and external hazards: collisions, fire, earthquake
Fire performance
Maintained performance in post-fire situation to obtain a dose rate compatible with the annual dosimetry objectives[70]</td></tr>
<tr><td>Support structure</td><td>Design for internal and external hazards: collisions, fire, earthquake
Fire performance</td></tr>
<tr><td>Containment of radioactive substances</td><td>Thermal protection</td><td>Disposal package protection
Fire performance</td></tr>
<tr><td>Evacuation of radiolysis gases</td><td>ILW-LL cask sweeping orifices</td><td>Deployment time compatible with time to reach criterion
Design for internal and external hazards: collisions, fire, earthquake</td></tr>
</table>

[70] Requirements defined in the external and internal exposure risks assessment

Safety function(s)	**EIP**		**Requirement defined for the EIP**
Protection from external and internal exposure	HLW casks	Containment	Design for internal and external hazards: collisions, fire, earthquake Effectiveness of radiological protection (compliance with dose rate) Maintained performance in post-fire situation to obtain a dose rate compatible with the annual dosimetry objectives[70] Fire protection
Protection from external and internal exposure Containment of radioactive substances		Support structure	Design for internal and external hazards: collisions, fire, earthquake Fire performance
Containment of radioactive substances	Ventilation of the surface installation C2, C3, C4		HEPA filters purification coefficient Compliance with a ΔP, a ventilation flow rate Maintain a certain level of extraction in the event of internal and external hazards: earthquake, loss of utilities, at Θ[71]7d Surveillance of filters head loss Filter casings as per standard NF ISO 17873 and the CETREVE recommendations
Evacuation of radiolysis gases		Ventilation networks of premises containing packages in the surface installation	Absence of dead zones
Containment of radioactive substances Evacuation of radiolysis gases	Ventilation of the ILW-LL zone Infrastructures of the underground installation exhaust air extraction shaft exit points		HEPA filters purification coefficient Compliance with a ΔP, a ventilation flow rate Filter casings as per standard NF ISO 17873 and the CETREVE recommendations Surveillance of filters head loss Maintain a certain level of extraction in the event of internal and external hazards: earthquake, loss of utilities, at Θ24h and Θ6h, tornado of intensity EF3 Restoration of ventilation post-fire, post-earthquake in a time compatible with the radiolysis risks assessment Backed-up mobile fans or redundant fans Backed-up ventilation of the electrical power supply Surveillance of nuclear ventilation (installation of anemometers to detect airflow head losses)

[71] See previous note
Long-duration minimum/maximum temperature (over at least 7 days)

Safety function(s)	EIP		Requirement defined for the EIP
Containment of radioactive substances	Handling resources liable to compromise the integrity of the packages: • Gantry crane in the train/truck bay; • Bridge crane for tipping the ET-V in receiving area 2; • ET-V transfer cart (elevation function); • Bridge crane for CP and CS-P in the ET-V unloading cell; • CS transfer elevator tables for CS and CS-P with cart; • ILW-LL handling cells elevator for ILW-LL disposal packages.		Maintain load in event of earthquake, loss of utilities, fire
Containment of radioactive substances	Package transfer devices: MLL, surface shuttles, underground cart, HLW and ILW-LL underground shuttles		Failsafe braking systems, automatic braking in the case of loss of electrical power supply or control systems Failsafe control system The emergency braking system must ensure stoppage before collision with an obstacle on the track No derailment
Containment of radioactive substances	Ramp transfer system (funicular) for ILW-LL or HLW casks	FAU and AUS emergency braking system	Triggering of the FAU and AUS according to the load Deceleration < 1 g Guaranteed braking capability in the event of an earthquake Anti-corrosion treatment and ability of tank and piping materials to withstand the action of the fluids carried or contained
		Cask immobilisation system	Cask does not tip under maximum acceleration/deceleration of 1 g and during an earthquake
		Rails	Guarantee the ability of the rails and their attachments to withstand an SMS Maintain rail continuity
		End of track buffers	Absorb the excess kinetic energy of the vehicle if uncontrolled speed up to 3 m/s Ensure vehicle deceleration of less than 1 g when it strikes them
		Interlocking between track power supply and detection of presence of shuttle or cart making it impossible for the shuttle to approach if the ramp transfer is not present	Maintain operation in event of earthquake, loss of utilities, fire

Safety function(s)	EIP	Requirement defined for the EIP
Protection from external and internal exposure	Monitoring of external and internal exposure	Measure dose rate and contamination Maintain monitoring function in the event of an earthquake, fire, loss of utilities, collision, etc.
Protection from external and internal exposure Containment of radioactive substances	Monitoring of radioactive releases	Measurement of releases Maintain monitoring function in the event of an earthquake, fire, loss of utilities, collision, etc.
Evacuation of radiolysis gases	Monitoring of H_2 concentration in the cells	Backed-up electrical power supply Maintain the function following an earthquake, fire, loss of utilities Monitoring air flow rates to guarantee an H_2 concentration below the thresholds (25% LEL in normal operation)
Evacuation of radiolysis gases	Backed-up network – Electricity generators	Power and duration to be defined Maintain the function following an earthquake

Table 5.3-2 List of EIP and additional associated defined requirements identified following the risk assessment, at the APS stage

Hazards	EIP	Requirement defined for the EIP
Protection against the fire risk	Fire detection	Permanent electrical power supply Seismic design basis Redundancy of the function
	Fixed automatic extinguishing systems	Seismic design basis Number and location of sprinkler heads Availability of extinguishing agent
	Fire safety zoning, fire compartmentation	Fire performance Closure of normally open doors/separations Seismic design basis
	Ventilation of underground drifts in the event of a fire	Backed-up electrical power supply Seismic design basis
	Refuges, safety recesses, personnel evacuation routes	Shelter from smoke Ambient temperature < 40°C Seismic design basis
Control of external flooding risk	EP1 building drainage system	Evacuate the water associated with a rise in the groundwater table
	EP1 building watertightness system	Ensure that the building is watertight
	Rainwater drainage networks	Avoid saturating the networks, which could lead to ingress of water into buildings containing EIP
	Watertightness systems on the shafts and at the top of the ramp	Ensure watertightness for a hydraulic pressure appropriate to the rock formations encountered
	System for collecting water seepage (aquifers)	Evacuate flow of water seepage Seismic design

VOLUME IV SAFETY OPTIONS RELATING TO CLOSURE OPERATIONS

1

Closure strategy

1.1 Principles

At the end of its operating life, the Cigeo waste repository will be closed by backfilling and sealing the underground facility. Following definitive closure (subject to obtaining statutory approval), humans and the environment will be protected against the risk of dissemination of radioactive substances and toxic elements in waste - which is Cigeo's fundamental purpose - by passive means that do not require human intervention.

In accordance with the regulatory framework, and in particular the Order of 7 February 2012, the facility will be closed at the end of its operating life and a post-operation monitoring phase initiated. Environmental monitoring will be conducted for a limited period, and on-site information storage systems implemented.

Once closed, Cigeo will perform post-closure safety functions. The closure structures will be designed to perform certain post-closure safety functions, and the related requirements, as specified in Volume II of DOS-AF[72] will enable the disposal system[73] to afford long-term passive safety.

According to Cigeo's master plan for operations, phased closure operations will be performed throughout the operating period preceding the facility's definitive closure[74]. The facility will be closed progressively, in accordance with a specific authorisation process. The purpose of the closure operations is to close off the disposal cells, backfill the drifts and sections, and lastly, seal the drifts.

A dismantling, closure and monitoring plan setting out methodological principles as well as the proposed steps and time-frame for dismantling the parts of the facility no longer required in order to operate the repository, close the disposal structures or monitor the facility will be submitted in support of the construction licence application.

The phased closure approach must not, however, be an obstacle to achieving the long-term passive safety objective. Accordingly, throughout Cigeo's operating life, and specifically during periodic safety reviews, an analysis - informed by the latest available knowledge, and in particular experience feedback relating to the facility's operation and monitoring - will be performed, to ensure that the closure steps in the baseline scenario are compatible with the objectives and enable the safety functions to be maintained post-closure.

The following objectives will be pursued throughout the phased closure process:

- Maintain the stipulated objectives and functions to ensure that the repository remains safe after being closed;
- Ensure safe operation, primarily by limiting the risks of co-activity between nuclear activity (during operation and disposal of waste packages) and carrying out works to construct the closure structures;
- Limit disruption caused by closure operations on waste disposal flows;
- Maintain disposal cell and disposal section monitoring provisions for an extended period (several decades);
- Implement a phased approach in order to acquire experience of closure operations;
- Maintain a high level of retrievability for an extended period (several decades);
- Optimise technical and economic aspects, in particular by striving for more efficient closure works by not splitting them.

[72] They contribute to Cigeo's post-closure fundamental safety objective, mainly by helping to impede water circulation inside the repository and retarding and attenuating radionuclide migration.
[73] In addition to its main component, the Callovo-Oxfordian geological layer, the post-closure disposal system includes the underground architecture and engineered components such as the waste packages and closure structures.
[74] The Act of 28 June 2006 states that Cigeo may not be definitively closed unless so authorised by an Act of parliament. According to the current schedule, definitive closure is planned for around 2150.

Under the master plan for operations, disposal cell closure operations will be carried out, section by section and disposal zone by disposal zone, before Cigeo is definitively closed. In practice, closing the facility will entail removing the operating equipment and building closure structures.

This chapter provides initial information relating to dismantling and closure operations and the related nuclear risks.

1.2 Dismantling operations

Cigeo's surface facilities will be dismantled when no longer of use.

BNI dismantling operations essentially include two types of activity:

- dismantling activated and contaminated equipment and managing the corresponding waste flows (collection, sorting, radiological measurements, processing and conditioning, followed by removal to appropriate outlets).
- cleaning up activated or contaminated concrete structures. The corresponding operations are generally performed after dismantling the equipment.

The principles and assumptions adopted for the purpose of assessing dismantling waste quantities are based in part on a "waste zoning" definition.

Cigeo is designed to minimise the quantities and radiotoxicity of the waste produced by optimising material choices and confining potentially contaminating substances. As a result, the surface facility houses very few processes liable to cause contamination (operations are largely limited to placing waste packages into containers and transferring packages). Only rooms used for waste packages are potentially waste-producing areas. The "waste" zoning is optimised and the number of equipment items installed in the nuclear area kept to a minimum. Furthermore, every possible effort is made to enable equipment to be upgraded and re-used as part of the maintenance strategy.

When facilities are shut down, the radiological status of rooms and equipment are assessed and recorded. Radiological spectra are produced to confirm the dismantling waste category. In the light of these preliminary tasks, a decision can be taken regarding the need to perform cleanup operations.

Concerning the dismantling of surface buildings, this consists in deconstructing:

- the building shell and finishings: cell linings, view ports, metal hatches, shielded doors, staircases, support structures, entrance doors, rails, etc. ;
- supply systems: electrical systems, utility systems and where applicable, buried systems;
- nuclear ventilation system in buildings.

Concerning the underground facility, equipment in useful parts of disposal cells in which waste packages are left in place (this applies for example to rails in ILW-LL cells). Elsewhere in the facility, equipment anchored or embedded in concrete (e.g. rails, cables, supports, foundation raft rebars, etc.) is also left in situ. The nature and preliminary estimated quantity of non-dismantled equipment and materials will be included in the Safety Analysis Report submitted in support of the construction licence application. In particular, their potential impact on post-closure safety function, and in particular the function "Avoid disruption to the Callovo-Oxfordian formation" (cf. post-closure safety functions described in Volume I of DOS-AF) will be assessed.

1.3 Underground facility closure operations

The following diagram illustrates the closure steps for the underground facility, and in particular the ILW-LL, HLW0 and HLW1/HLW2 sections, as defined in the current version of the master plan for operations (7).

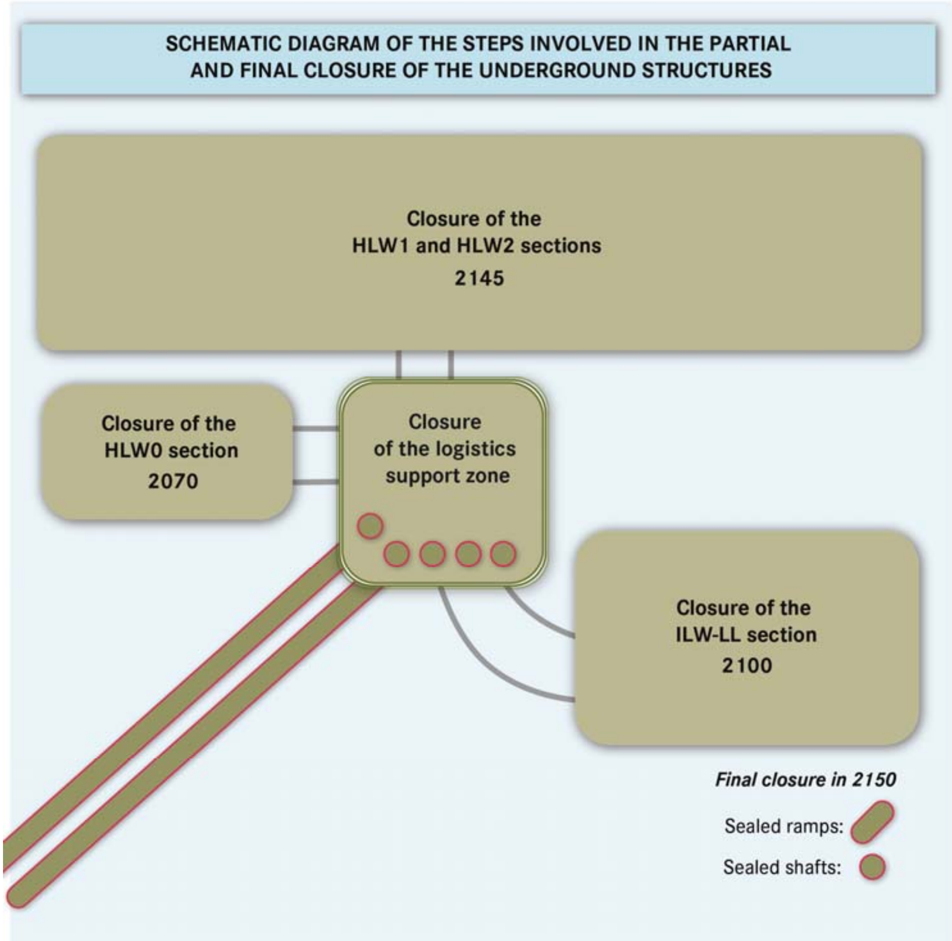

Figure 1.3-1 Diagrammatic representation of the closure steps for the underground structures (forecast dates at end of preliminary design studies)

When closing the underground facility, the work will include "dismantling" operations (equipment removal) followed by relatively heavy "civil engineering" operations (e.g. constructing concrete structures measuring a metre or even several metres in thickness and cross-section, placing large quantities of backfill, etc.).

These closure structures use spoil for backfill and clay materials for sealing. The following sections of this document contain a few diagrams illustrating these structures.

Drifts will be backfilled with clay removed during the excavation of the repository and stored in muck piles at the surface.

Each section is closed in a single operation that consists in building the plugging structures for all disposal cells and backfilling and sealing the drifts used for the closure operation.

As closure operations are major works, the risk relating to co-activity by the structural work and operating activities is factored into the design. During closure operations, when the disposal cells are full, the risks relating to external and internal exposure are factored into the design, and in particular the radiation protection plug that must be installed.

Once the cells have been closed, the active systems implemented to manage operational risks will no longer be operational. This applies in particular to the ventilation systems that remove H_2 from ILW-LL cells (cf. radiolysis risk), and the systems that remove water from the HLW cell (cf. risk relating to water build-up inside the cell).

The post cell-closure risks are identified and the safety options adopted at this stage described in Chapter 2.

1.4 Definitive closure

Cigeo will be definitively closed by backfilling the final drifts in the logistics support area, and by sealing and backfilling the shafts and access ramp (see figure above).

During the definitive closure operations, the seals, featuring cores of swelling clay, are placed in the shafts and ramps in the upper part of the Callovo-Oxfordian layer (i.e. the “roof” of the host rock formation). The shafts are then backfilled to the surface. The surface facilities are then dismantled.

The seals in surface-to-bottom connecting structures play a major role in post-closure safety, as described in the ASN’s 2008 Safety Guide, which states: “The surface-to-bottom connections and possibly some drifts and certain structures within the repository will require seals to ensure water-tightness to a specified quality level.”

Chapter 3 in Volume II of the Safety Options Report – Post-closure Part stipulates the required functions and performance of such seals.

In view of the importance of these components, this consideration is included in their design.

Andra also plans to build a seal demonstrator as part of the pilot industrial phase even though the repository will not be closed until the end of its operating life.

2

Closure operations

2.1 Closure structures

The closure structures consist of backfill and seals. Cigeo's seals are classified in three broad categories (cf. Safety Options Report - Post-Closure Part):

- vertical seals;
- inclined seals;
- horizontal seals.

Vertical and inclined seals belong to the "surface-to-bottom connection" category whereas horizontal seals belong to the "disposal area seals" category. The intended solutions are described hereafter. Three types of seal are planned for Cigeo:

- surface-to-bottom connection (LSF) seals, located as follows:
  - ✓ in the Callovo-Oxfordian layer's silty-carbonated unit (USC), in the case of ramp seals;
  - ✓ in the Callovo-Oxfordian layer's transition unit (UT), in the case of shaft seals;
- seals in connecting drifts in the underground facility, installed in the Callovo-Oxfordian layer's clay unit (UA).

The requirement and corresponding means of sealing the ILW-LL waste disposal cell air inlets and returns, in the Callovo-Oxfordian layer's clay unit are also studied.

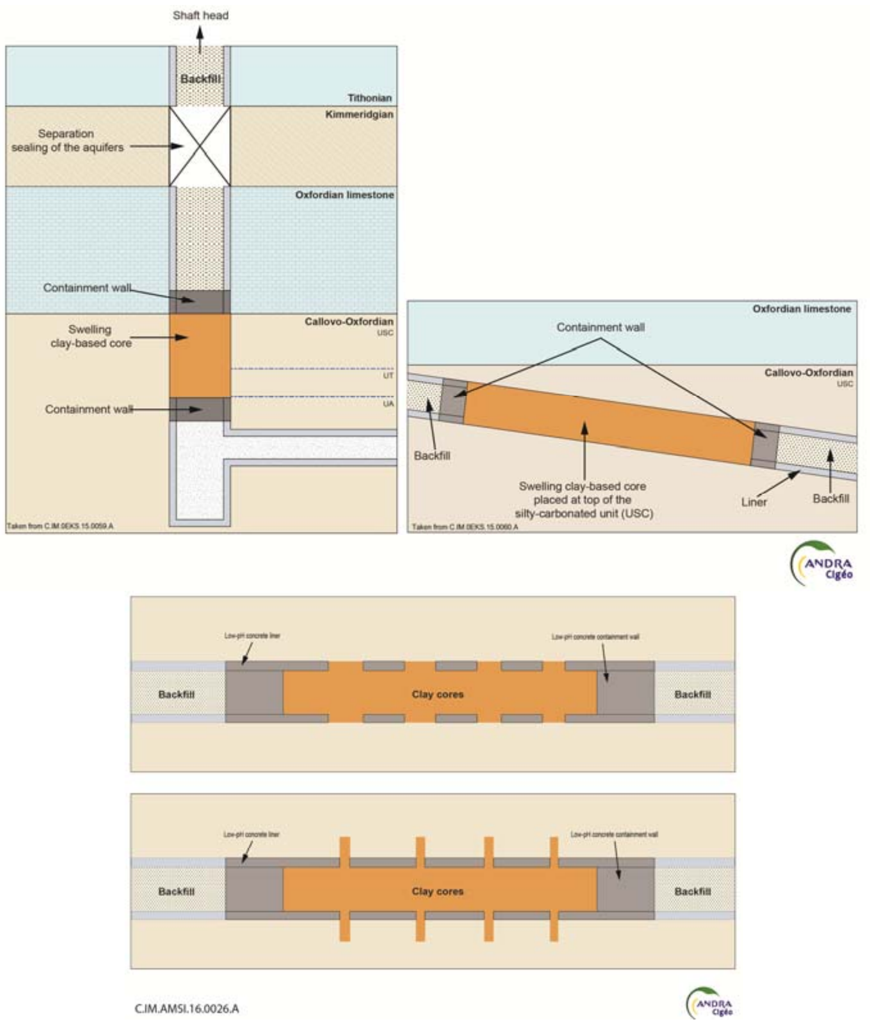

Figure 2.1-1 Block diagrams of the inclined, vertical and horizontal closure structures

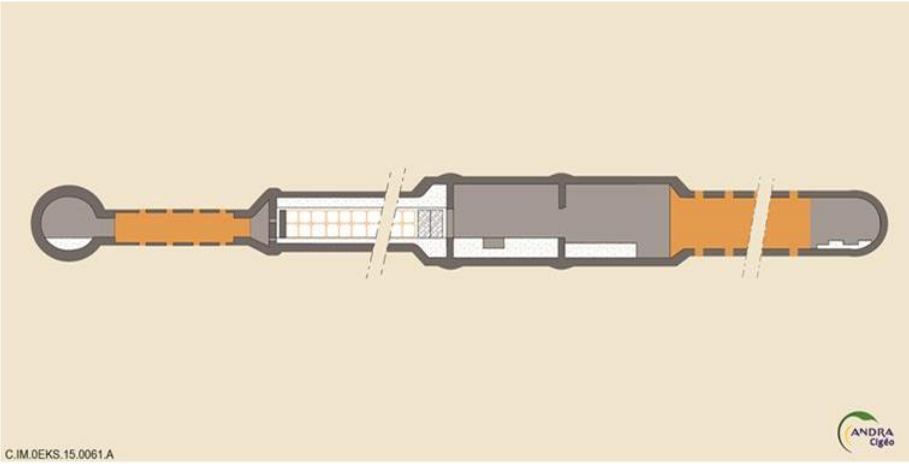

Figure 2.1-2 Diagram representing an ILW-LL cell closure – Sample illustration showing the seals (at the end of the preliminary design studies stage)

Concerning the HLW cell, the closure system located in the HLW cell head between the access drift and the last disposal package placed in the cell consists of:

- radiation protection plug;
- clay plug filling the HLW cell head, in order to durably maintain physicochemical conditions conducive to the protection of vitrified waste and minimise any residual voids in the HLW cell head when the material is placed;
- a section of sleeve long enough for the cell closure.

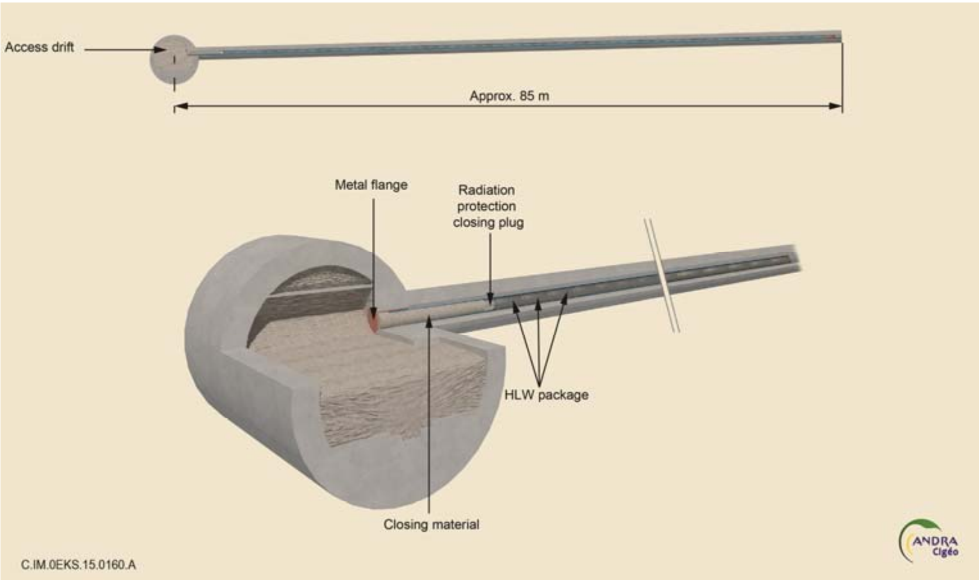

Figure 2.1-3 Block diagram representing a plugged HLW0 cell and backfilled drift in an HLW cell section

2.2 ILW-LL cell closure

2.2.1.1 Preliminary operations before closing the ILW-LL cell

Note concerning equipment in the ILW-LL disposal cell's hot cell: when a disposal cell is full, equipment is removed and mothballed within around one year of the end of filling. All monitoring equipment and all safety-related equipment is kept operational until the cell is plugged as part of the repository's partial closure operations. Radiation protection devices are installed to enable operations in the ILW-LL section to be conducted in compliance with radiation protection objectives. Rails and other equipment anchored in a disposal cell's concrete foundation raft or support structures are left in place. At this stage, a wall of concrete blocks is erected at the head of the usable part of the ILW-LL disposal cell, between the final row of packages and the hot cell protection door. The wall is designed to satisfy the stipulated dose-related requirements, to enable operational activities to be conducted in the underground facility. The ILW-LL cell remains ventilated.

When the ILW-LL cell is closed, any equipment in the hot cell, the docking area and the access drift not removed at the end of the cell filling phase (such as rail track in the drift) and any mothballed equipment is removed and disposed of[75].

For these operations, a work area is set up in the disposal cell's access drift, the interface between the access drift and the connecting drift being isolated by means of a temporary airlock or wall. This wall nevertheless enables requirements and necessary utilities, including ventilation, to be maintained post-closure.

Similarly, the air return shaft and any other equipment that cannot be left in situ is removed from the air return cross drift at the other end of the disposal cell. The disposal crane's running track is left in situ, together with all related anchoring systems in the disposal cell, as well as the disposal crane's position referencing systems and electric power cable supports (e.g.: diabolo)[76].

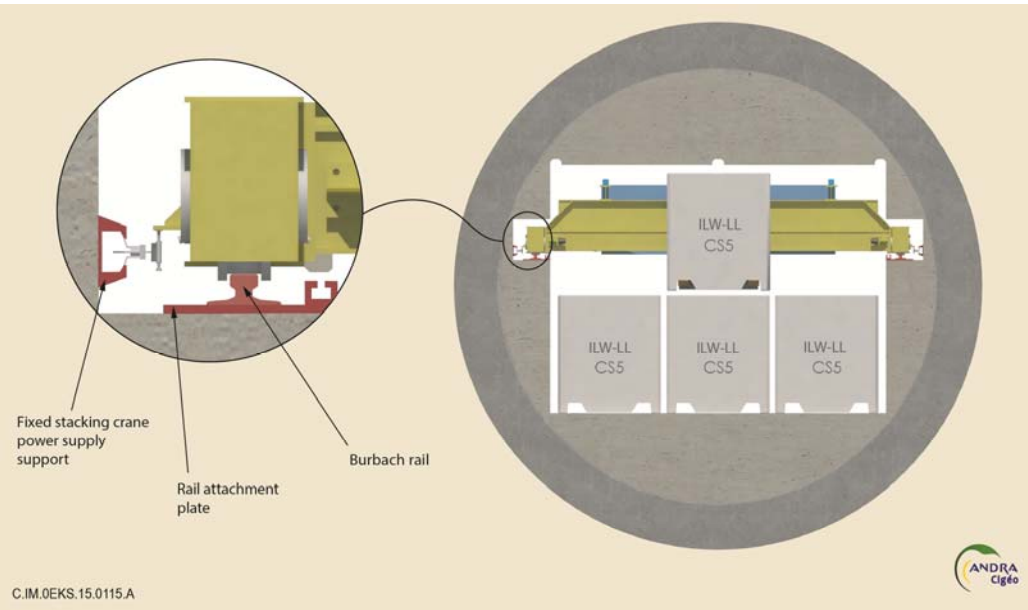

Figure 2.2-1 Detail showing the rails left in the disposal cell (at the preliminary design studies stage)

[75] If this is done before the ILW-LL section has been completely filled, any work in the ILW-LL hot cell may require operations in the connecting drift to be shut down.
[76] These running tracks are designed to be reused by the crane in the event of a retrieval operation (cf. DORec).

Anchor systems attached to the main structure are also left in place. This avoids damage to the main structure and the handling airlock structure. Components that are embedded in the concrete of the main structure or the handling airlock structure are not removed, to avoid damaging the concrete.

Any equipment not liable to be reused may be left in place - provided that it does not create voids and that the corresponding surface areas and weights of steel would not generate significant quantities of hydrogen by anoxic corrosion, compared with the volumes of hydrogen produced in the disposal cells connected to the drifts - and more generally, all components embedded in concrete are also left in place[77]. This aspect will be addressed in greater detail in the context of the construction licence application, in the light of impact assessments relating to disruption in the Callovo-Oxfordian layer and in particular, to the post-closure safety functions.

2.2.1.2 Plugging and backfilling the hot cell and docking area

Each ILW-LL disposal cell will be plugged beginning at the access drift side by erecting a concrete wall, forming a leaktight seal with the wall of the former radiation protection door. On the air return drift side, the concrete wall is erected at the end of the air return cross drift, near the ventilation baffle, to close off the various openings. As a result, ventilation inside the ILW-LL disposal cell ceases after this operation. An atmospheric monitoring system may be installed on the access drift side of the plugging wall at this stage, to facilitate subsequent analysis of the atmosphere inside the disposal cell. The role of such a system includes monitoring for H_2 in order to enable appropriate protective measures to be taken to prevent explosion risks in the event of a decision to retrieve waste packages from the ILW-LL cell and dismantle the closure structure (see Chapter 2).

Plugging continues by closing the section between the plugging wall and the connecting drift. The hot cell and docking area are completely backfilled to limit long-term deformation around these large cavities.

2.2.1.3 Backfilling the section of drift at the two ends of the disposal cell

Two options are currently under consideration regarding backfilling the drift at the disposal cell entrance and the air return interconnecting drift: fitting a seal with a core of swelling clay or carefully installing backfill consisting of excavated clay rock to ensure good hydraulic performance.

2.3 Closing the HLW cell

2.3.1.1 Preliminary operations before closing the HLW disposal cell

As soon as a disposal cell has been completely filled, a radiation protection closure plug is placed inside the cell lining, as close as possible to the emplaced packages. This plug is left in place until the disposal cell is passed and remains in place when the cell is plugged. It is designed on the basis of radiological zoning adopted for cell closure and package retrieval operations and in compliance with dose rate objectives in a drift for accessing HLW disposal cells.

[77] . Such items will therefore be available for reuse in the event of a subsequent retrieval operation (cf. DORec).

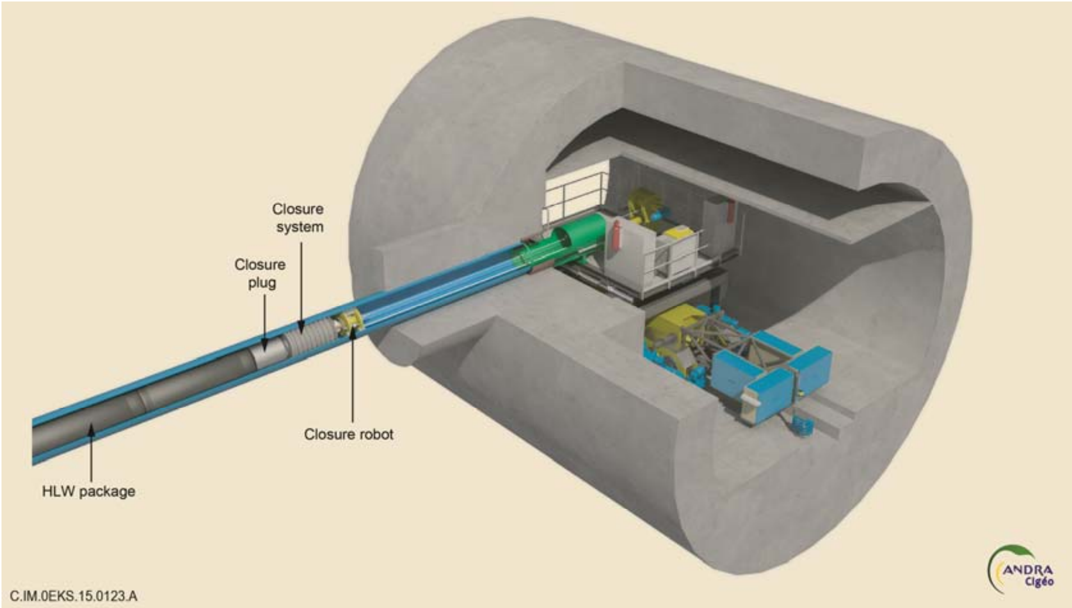

Figure 2.3-1 Illustration of a twin HLW disposal cell closure operation0

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2.3.1.2 Closure operations: plugging and backfilling the disposal cell head

The water extraction system is installed before committing to the closure operation.

In HLW disposal cells, the equipment left in place with the waste packages includes spacers[78] in the usable part, as well as equipment used for radiation protection and to close the disposal cell at the cell head (i.e. the radiation protection plug and where applicable, the closure system). The closure system, illustrated here by a bellows, is designed to withstand the load exerted by the plugging material placed when closing the disposal cell, and to prevent it from spreading into the usable part. It is installed after the disposal cell has been loaded.

When the HLW disposal cell is closed, the interior of the HLW cell heads is uniformly filled with a clay material having a near-neutral pH, to form a physicochemical environment conducive to the protection of vitrified waste. This material may be introduced into the HLW disposal cell either through the flange or else directly, if the flange is temporarily removed.

In principle, introducing the filling material through the flange more effectively limits the ingress of oxygen into the disposal cell, but the HLW cell head will be harder to fill uniformly. If the flange is removed for the filling operation, the material may be placed in the form of compacted blocks.

Additionally, the clay material will gradually resaturate following shutdown of the water extraction system. The gas extraction system may remain operational, if needed, in the event of excessive gas pressure (by water vapour or hydrogen) in the HLW disposal cell.

[78] The main function of the spacers is to physically separate the waste packages, in order to ensure that their heating power is distributed uniformly throughout the disposal cell and ensure compliance with the maximum linear power density criterion. This is why such objects are only present in HLW1/HLW2 disposal cells. Spacers are designed to remain intact and be handleable throughout the operating phase.

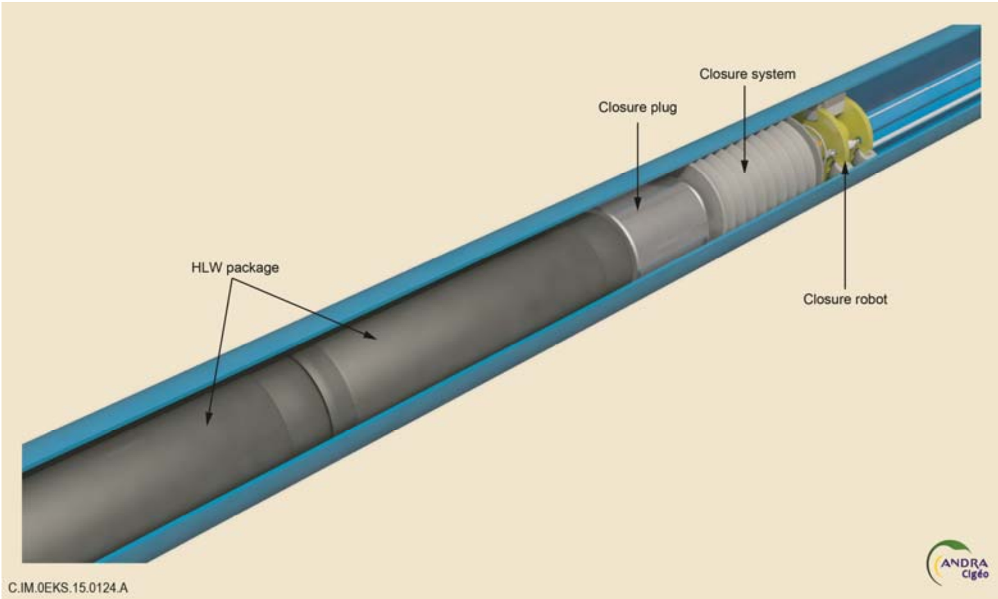


Figure 2.3-2 Illustration representing a HLW disposal cell closure system0

Studies will be conducted during the detailed engineering design phase, to define the closure system illustrated here by a bellows, and to optimise the disposal cell plugging operations and the radiation protection plug left in place in view of their potential impact on post-closure safety. Note that the first industrial operations to close HLW0 disposal cells are planned around 2070.

Closure tests on an HLW disposal cell demonstrator are planned during the pilot industrial phase, based on the detailed design for the HLW disposal cell adopted for the construction licence application.

2.4 Closure of sections and connecting drifts

Sections are closed by backfilling the operating and works-related connecting drifts, interconnecting drifts and return air drifts, and by installing a seal in planned locations in each connecting drift and return air drift near the operating logistics support zones (cf. Figure 2.4-1).

Wherever possible, closure operations are performed in free access areas.

Backfill is placed in the drift and compacted to limit any residual voids and the extent of delayed surface convergence. Before the drifts are filled, any atmospheric monitoring and gas extraction systems in the disposal cells are disabled.

Repository sections are fitted with closure seals to comply with post-closure safety requirements (cf. Chapter 3 of Volume II of the Safety Options Report – Post-Closure Part). The locations of such seals remain to be determined.

The diagram below illustrates their positioning in the underground facility after Cigeo has been definitively closed.

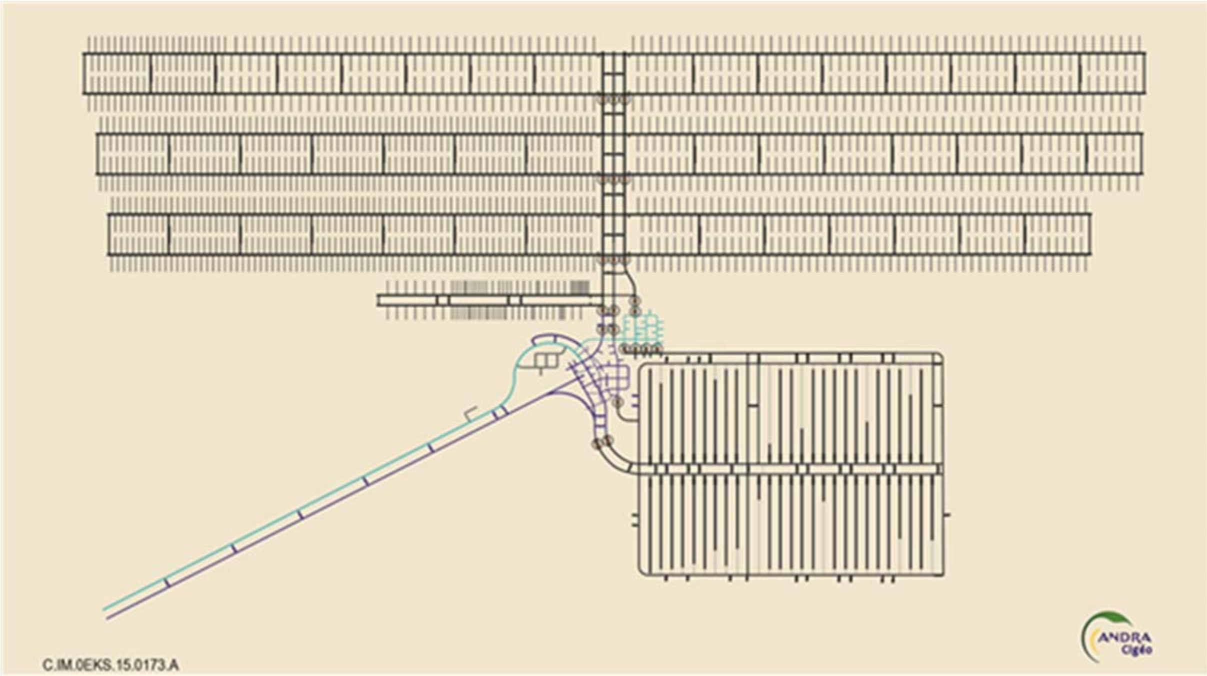


Figure 2.4-1 Illustration of the seal locations in the underground facility

2.4.1.1 Preliminary operations before backfilling

Before backfilling, operations are performed to retrieve operating equipment present in the structures that are to be filled.

In addition, the ventilation in the connecting drifts, interconnecting drifts and return air drifts is shut down and the corresponding equipment removed. Temporary ventilation is installed for the backfilling operations.

As in the hot cell, the docking area and the ILW-LLL disposal cell access drift, any equipment (except in sealing areas) that is unsuitable for reuse at the Centre or at other nuclear installations and might form radioactive waste is left in situ, as specified previously (see Section 2.2.1.1).

2.4.1.2 Drift backfilling and sealing

The backfill material for the drifts largely consists of excavated rock stored on the surface in muck piles pending reuse. Before being placed, the reused clay rock is processed to regulate the particle size distribution and ensure that the water content and mechanical properties of the backfill material comply with specifications. These specifications are determined so as to facilitate compaction, and minimise the backfill material's compressibility and maximise its dry density[79], allowing for technical and economic placement limitations.

[79] Dry density in the soil mechanics meaning of the term: mass of solid matter per unit of volume of in situ material.

The Richwiller backfilling demonstrator proved that backfilling drifts with clay rock is feasible. Experience feedback from the drift backfilling demonstrator confirmed the dry density target of at least 1.7[80] and the phasing of the backfilling operation: horizontally compacted lower layers on the foundation raft, upper layers compacted in sheets on sloping surfaces (from 1H/1V to 2H/3V).

A faster industrial compaction system better suited to the dimensions of the structures to be backfilled remains to be developed, in particular for compacting backfill near roof level. However, due to the 8 m internal diameter of Cigeo's disposal cells, it may be possible to use conventional earthworking machinery to backfill and compact drifts to a height of 4 or 5 metres, with materials being brought in by a conveyor belt or pneumatic conveyor.

Drift backfilling proceeds from the rear of the sections towards the logistics support zones.

2.5 Closure of shafts and ramps

Equipment is removed from drifts, recesses and interconnecting drifts in operating and works logistics support zones and surface-to-bottom connections (shafts and ramps) in the same way as when closing drifts in the ILW-LL section, and temporary ventilation is installed for the closure works phase.

Shaft bottoms are filled with a rigid concrete material to form a containment wall that will support the clay sealing core in the upper part of the host layer, in order to comply with post-closure safety requirements. (The seal will be inspected during the acceptance procedure).

At the foot of ramps, clay rock-based backfill is placed in a similar procedure to that described for the drifts; however, the slope of the ramp requires the filling material to be compacted on an incline relative to the structure's foundation raft, at gradients slightly different to those planned for the drifts.

Surface-to-bottom connections are sealed with swelling clay-based seals designed to ensure low permeability to water. As these seals also fulfil the post-closure safety requirements (and will be inspected during the acceptance procedure) are placed such that the clay core is at the interface with the most highly-carbonated clay rock geological units (namely the silty-carbonated unit (USC) and the transition unit (UT)). In shafts, the core will extend for a thickness of 40 m in the USC and the upper part of the UT, and in ramps, it will extend for at least 100 m through the upper part of the USC.

To ensure that the swelling clay in the sealing core makes direct contact with the clay rock, the liner in shafts and ramps will be removed when the seal is installed, although this may require load-bearing rings to be installed at intervals. Liners may be removed using similar methods to those adopted for drift seals. Special-purpose equipment may also be developed, in view of the considerable length of liner to be removed, as has already been done in tunnels (Tunnel Dismantling Machine).

In view of the more highly carbonated nature of the Callovo-Oxfordian layer where the swelling clay plugs are to be introduced, it may be possible to support the walls simply by bolting (without shotcreting) before fitting the clay core, in a similar approach to that planned for the drifts.

These initial seals are supplemented by additional seals installed at the interface with the Kimmeridgian layer. The purpose of the latter is to limit the circulation of water between the various transmissive levels in the Oxfordian limestone and the Barrois limestones of the Tithonian formation, in accordance with the French Environment Code.

[80] Value corresponding to 95 % of the Normal Proctor Optimum.

2.6 Experience feedback relating to seal installation

Andra conducted the Full Scale Seal (FSS) trial as part of the Demonstration Of Plug And Seal (DOPAS) EU project aimed at gaining initial experience of the construction of a horizontal sealing structure(5).

The FSS trial, conducted in 2014 in Saint-Dizier, featured the industrial construction of a horizontal seal. This prototype's dimensions are representative of the seals liable to be installed in Cigeo drifts.

The following figures contain selected views of the seal construction process (including final dismantling to obtain post-construction data).

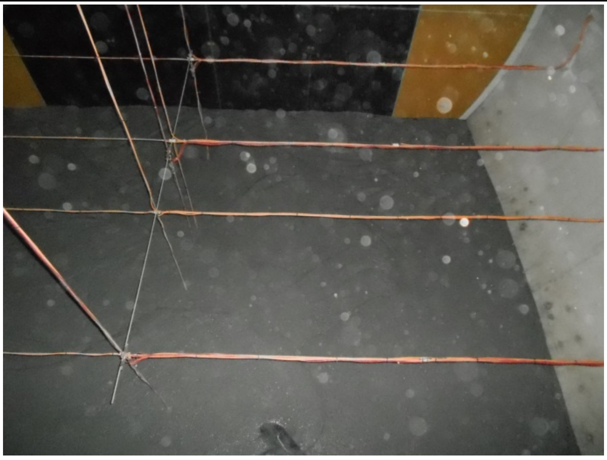
	
Concrete mock-up of the drift to be sealed	Casting the low-pH self-placing concrete
	
End of the upstream block of self-placing concrete	Bentonite core placing machine

Figure 2.6-1 Selected photos of the seal trials conducted by Andra

3

Inventory of closure operation-related risks and risk management measures

This chapter describes, at this stage, a preliminary assessment of the principal risks that must be studied with regard to closure operations. This assessment did not reveal any critical elements liable to prevent successful completion of closure operations as described in Chapter 2. These operations will be described at a later date, and will be subject to a specific authorisation procedure.

3.1 Internal nuclear risks

The purpose of the closure operations is to gradually implement - beginning by closing the disposal cells and ending with the ramps and shafts - passive measures to ensure safety after the facility has been closed.

The passive nuclear risk management measures implemented for the first stage that consists in closing the disposal cells enable the operational safety functions to be managed during all closure stages (including closure of the sections and then the ramps and shafts). The nuclear risks are focussed in the disposal cell, in the immediate vicinity of the waste packages. The closure operations described hereafter do not involve the waste packages or operational safety functions.

3.1.1 Risks relating to the ILW-LL area

3.1.1.1 External exposure risk

Protection against the risk of external exposure is provided by implementing static radiation protection, afforded by:

- a wall of concrete blocks erected at the head of the usable part of the disposal cell, between the final row of packages and the hot cell protection door. This wall is erected when the disposal cell has been filled. This protective measure is designed based on the radiological zoning adopted for the disposal cell plugging and waste package retrieval operations;
- a radiation protection wall located at the rear of the disposal cell. This wall is installed when the disposal cell is plugged.

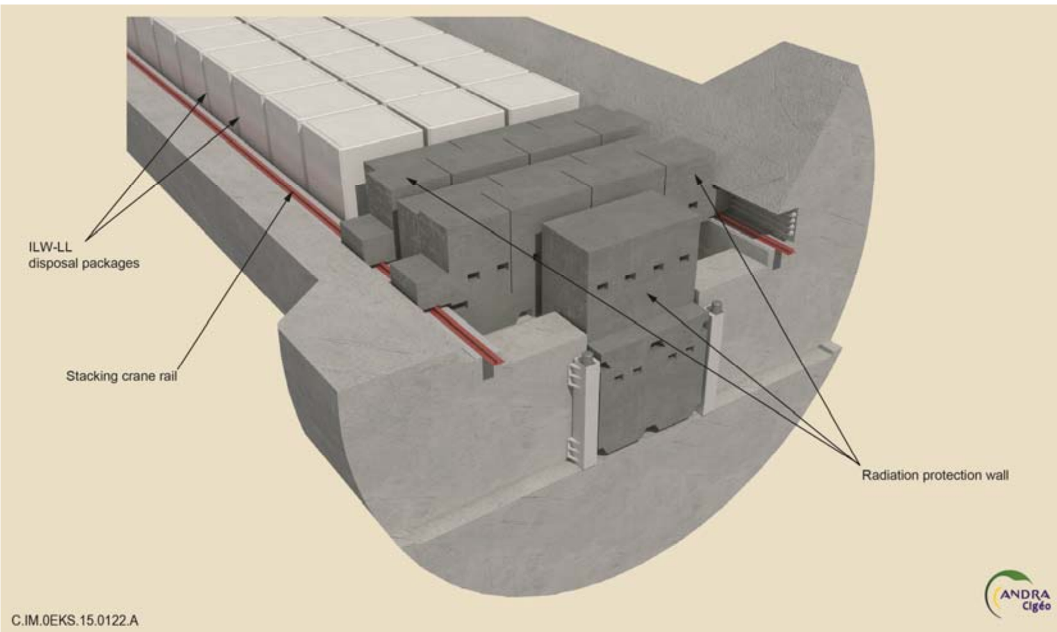


Figure 3.1-1 Block diagram representing the radiation protection wall erected when filling is complete

Radiation measurements are maintained in the access drifts and connecting drifts after the disposal cell has been closed.

3.1.1.2 Dispersion risk

The containment principles described in Volume III apply to the ILW-LL disposal cell throughout the facility's operating life, whether or not the cell is ventilated.

The ILW-LL disposal cell is ventilated until the plugging operations are performed (see Section 2.1.2.3). The containment systems are the same as for the emplacement operations (cf. Volume III § 2.1.2), i.e. the waste packages form a primary containment system and the structure of the disposal cell and related nuclear ventilation installation form a secondary containment system.

Before the disposal cell is plugged and the return air drift is backfilled (cf. & 2.2.1.3), the disposal cell is configured for static containment by installing a semi-rigid containment airlock in the access drift and closing the fire dampers.

When the disposal cell has been closed and is unventilated, the two containment systems are as follows:

- the waste disposal package remains the first containment system;
- the structure of the disposal cell, combined with a closure structure (that provides static containment at disposal cell level), together form a second containment system.

The following assumptions apply in the ILW-LL disposal cell's normal operating range:

- radioactive gases may be released;
- radioactive aerosols contained in disposal packages are not dispersed. When an ILW-LL disposal cell has been filled but no operations have been performed, given the rugged design of the disposal packages and the favourable environmental conditions in the ILW-LL disposal cells, the risk of loss of containment involving a significant number of disposal packages in the ILW-LL disposal cell before the end of the operating phase (in around 2150) is precluded. Damage to a limited number of disposal packages in the disposal cell is, however, taken into consideration in the design basis for the closed cell. The favourable conditions in the ILW-LL disposal cell (in terms of its mechanical integrity throughout the operating period and the absence of circulating water) and the closure structure combine to prevent dispersion outside the disposal cell.

When the disposal cell is closed, ambient contamination measurements are stored and remain operational in the rest of the facility. Such instruments will be removed gradually as the closure operations progress (closure of the access drift followed by the connecting drifts).

3.1.1.3 Heat transfer risk

Heat generated by ILW-LL waste is removed passively during the operating period (the ventilation system has no bearing on compliance with requirements relating to the temperature of concrete and equipment in the ILW-LL disposal cell). Accordingly, even with the ILW-LL disposal cell closed and unventilated, the design options enable compliance with temperature requirements.

Temperature measurements are maintained in the access drifts and connecting drifts after disposal cells have been closed.

3.1.1.4 Waste radiolysis risk

The safety option adopted for Cigeo facilities consists in precluding the risk of explosion throughout the operating life. All necessary precautions must be adopted to prevent the formation of an explosive atmosphere in normal operating conditions, after a loss of ventilation or after closure of a disposal cell.

During the phase in which ILW-LL cells are ventilated (i.e. until the disposal cell closure operations, see § 2.1.2.3), the nuclear ventilation system removes any radiolysis gases produced by waste packages (cf. Volume III § 2.1.5.5).

The transitional phase during which the ILW-LL disposal cell's ventilation system is shut down during the closure operation entails:

- controlling ventilation such that cell closures can be managed without the atmosphere in the disposal cell becoming explosive during closure, and maintaining cell ventilation pending closure;
- designing the ventilation system to provide the necessary ventilation flows throughout the underground facility.

By the time disposal cell ventilation is shut down, releases of radiolysis gases from waste packages will have tapered off, and some of the gas will dissipate through the walls. These releases and the dissipation process have not been quantified at this stage. Andra has set up a research programme to study these aspects, with the following aims:

- describe the hydraulic/gas transient in unventilated ILW-LL disposal cells and identify conditions liable to form an explosive atmosphere (considering the nature of the emplaced packages, the disposal cell geometry, etc.);
- assess the performance of inerting systems: checking that “oxygen consuming” or “flushing” provisions implemented when disposal cells are closed preclude the risk of an explosive atmosphere forming in the period following ventilation shutdown;
- identify the characteristics of an explosion (pressure, temperature, flame velocity, etc.), assess its consequences and evaluate compensating solutions.

In the light of this research, specific measures may if necessary be proposed within the construction licence application framework.

Hydrogen content monitoring measurements have been specified in order to check the hydrogen content in the ILW-LL disposal cell before proceeding with closure operations. Once the ILW-LL disposal cell has been closed (and is unventilated) hydrogen content measurements will be maintained in access drifts and connecting drifts. Solutions under consideration include inerting the disposal cell and leaving a system in the ILW-LL disposal cell closure structure that would facilitate the reinstallation of a ventilation system able to remove hydrogen if the cell were to be reopened.

3.1.1.5 Criticality risk

The safety requirements and options are the same as for disposal cells that are being loaded or are full and closed during the operating phase (cf. criticality-related sections of Volumes I and III). The criticality risk remains limited, due to the geometric durability of the disposal packages throughout the operating life and the design measures adopted (arrangement of primary packages in the disposal container, arrangement of disposal packages in the disposal cell, etc.).

3.1.2 Risks relating to the HLW0 area and HLW1/HLW2 area

3.1.2.1 External exposure risk

The external exposure risk is addressed via static radiation protection afforded by installing a radiation protection closure plug inside the disposal cell’s lining, in the immediate vicinity of the emplaced packages. The plug is installed after a disposal cell has been filled. It is designed on the basis of radiological zoning adopted for cell closure and package retrieval operations and in compliance with dose rate objectives in a drift for accessing HLW disposal cells.

3.1.2.2 Dispersion risk

HLW disposal packages are designed to confine waste until at least the end of Cigeo’s operating period (cf. Volume III § 2.1.2).

3.1.2.3 Heat transfer risk

Heat generated by HLW waste is removed passively (cf. Volume III § 2.1.4).

3.1.2.4 Criticality risk

The safety requirements and options are the same as for disposal cells that are being loaded or are full and closed during the operating phase (cf. criticality-related sections of Volumes I and III). The criticality risk remains limited, due to the geometric durability of the disposal packages throughout the operating life and the design measures adopted (arrangement of disposal packages in the disposal cell, weight limitations, etc.).

3.2 Risks relating to internal and external hazards

3.2.1 Shock/collision risk

At this stage of the studies, the following handling solutions have been adopted for transferring waste flows from the surface to the disposal point:

- means of transport located on the service ramp or in disposal areas:
  - ✓ a special-purpose vehicle on the service ramp;
  - ✓ three special-purpose vehicles in each disposal area:
    - a transfer cart in the connecting drift, using the disposal area cart infrastructure;
    - a transfer cart in the access drift, using the disposal area shuttle infrastructure;
    - a transfer cart in the air return drift (to be defined);
- these vehicles will be able to carry the three types of handling unit thus far defined (concrete mixers, material bins and transport platforms). These vehicles are autonomous and designed to enable load transfers.
- load transfers between means of transport take place:
  - ✓ between the bottom of the service ramp and the logistics support zone, the handling unit is transferred using the existing bridge crane;
  - ✓ between the connecting drift and the access drift leading to the disposal cells in the HLW sections;
  - ✓ between the logistics support zone in the operational area and the air return drift.

Closure operations may be a source of shock and collision risks (involving means of transport and handling units). According to the same principle as for the handling equipment used to emplace packages, measures have been adopted to limit shock and impact risks involving equipment used to perform closure operations. Similarly, the facility’s safety systems are designed to withstand the consequences of a shock or collision. At organisational level, measures have been defined to avoid damaging:

- radiation protection in and around HLW disposal cells and ILW-LL cells;
- equipment providing dynamic containment in the ILW-LL disposal cell (i.e. the cell’s structure and ventilation system) as well as the subsequent static containment (closure structure);
- the ventilation system that removes radiolysis gases from the ILW-LL disposal cell during the ventilated phase;
- post-closure EIPs.

A vehicle flow management program will also be implemented.

3.2.2 Fire risk

Closure operations may be a source of fire risks relating to the handling and transfer equipment used, as well as the processes used for such operations (welding, cutting, etc.). According to the same principle as for the handling equipment used to emplace packages, measures have been adopted to limit the risk of a fire outbreak and subsequent development involving equipment used to perform closure operations. Similarly, systems are designed to withstand the effects of fire. At organisational level, measures have been defined to avoid damaging:

- radiation protection in and around HLW disposal cells and ILW-LL cells;
- disposal packages;

- equipment providing dynamic containment in the ILW-LL disposal cell (i.e. the cell's structure and ventilation system) as well as the subsequent static containment (closure structure);
- the ventilation system that removes radiolysis gases from the ILW-LL disposal cell during the ventilated phase;
- post-closure important components (cf. Volume IV of the Safety Options Report – Post-Closure Part).

Removing operating equipment may require hot work, subject to hot work permits.

Handling units enabling the necessary concrete and materials for closure operations must comply with fire requirements. The technology employed for such handling units remains to be defined, although it may be based on technology used for the (rail-mounted) disposal area transfer carts.

Equipment used for closure operations (plant, saws, consumables, jack-hammers, etc.) must comply with fire design requirements (fire detection and extinguishing systems aboard handling machinery, limited fire loads during closure works, etc.)

In view of the closure-related traffic flows potentially carried by the service ramp, a number of design requirements applicable to handling and operating equipment have been adopted for closure operations involving the service ramp:

- no more than one vehicle in the service ramp, whether ascending or descending (no crossings) to ensure that any personnel on the ramp are only located near the vehicle;
- limitation on the maximum heat output of a potential fire on the ramp;
- adaptation of the ramp's emergency response facilities to the transfer method[81];
- service ramp suitable for use by Cigeo incident response vehicles.

A number of measures have also been adopted to ensure that closure operations do not block incident response vehicle movements, including:

- implementing a vehicle traffic management system in the underground facility;
- limiting the time that handling units remain in drifts;
- limiting obstruction of handling units;
- if necessary, suspending operational activities during the closure operation.

3.2.3 Loss of ventilation risk

The ventilation system removes radiolysis gases from the ILW-LL disposal cells. Consequently, any loss of ventilation may present a risk of an explosive atmosphere forming in ILW-LL disposal cells awaiting closure.

During the various closure phases, disposal cells awaiting closure are ventilated without interruption.

3.2.4 Co-activity risks

The following activities coexist during closure operations in the HLW0 area[82]:

- ILW-LL package emplacement operations, including ILW-LL disposal cells that have already been filled (operational area);
- ILW-LL disposal cell and HLW1/HLW2 disposal cell construction operations (works area).

The following activities coexist during closure operations in the ILW-LL area[83]:

- HLW1/HLW2 package emplacement operations, including HLW disposal cells that have already been filled (operational area);
- HLW1/HLW2 disposal cell construction operations (works area);
- the HLW0 section is considered to be closed.

[81] The transfer method will be chosen during the detailed engineering design process.
[82] Scheduled to begin in 2070, according to the master plan for operations
[83] Scheduled to begin in 2100, according to the master plan for operations.

The risks relating to co-activity between operational areas and works areas (disposal cell/cell construction activities) are studied in Volume III.

The risks relating to co-activity involving emplacement operations and closure operations in operational areas concern:

- closure of the HLW0 area / emplacement in the ILW-LL area;
- closure of the ILW-LL area / emplacement in the HLW/HLW2 area.

Although performed simultaneously, these operations are spatially separated. They require coordinated management of traffic flows by vehicles used respectively for closure operations and for disposal operations. Alternate routes may also be envisaged, for example by creating additional drifts or modifying the original infrastructure design, with the aim of preventing closure-related traffic flows from passing through the carousel or drifts while disposal activities are being conducted.

Closure-related traffic flows pass through the following areas:

- the “operations” surface-to-bottom connection;
- the “operations” logistics support zone;
- connecting drifts;
- access drifts.

These four areas are located in the operational area and are subject to specific rules and restrictions, including:

- limitations on the fire load of handling equipment in drifts;
- limitations on gauges in the various types of drift, in drift intersections and on turntables;
- gradient limits, in particular along the service ramp;
- rolling surfaces: rails, turntables and gutters;
- a set number of vehicles per section;
- etc.

Furthermore, temporary work areas are set up for closure operations, enabling the planned closure operations to be performed independently from the rest of the facility. The measures adopted at this stage is to replicate the ventilation and smoke removal utilities that are to be dismantled with a new “work site” system that will be connected upstream before the start of dismantling works. By this means, a “confined” work space is defined, ensuring that nuisance caused by closure operations do not disrupt the rest of the operational facility. Ventilation in this space is appropriate to the work site conditions, particularly in terms of dust build-up and heat removal. A dedicated filter system enables this ventilated confined space to be limited, with air being discharged into a full-bore section of the connecting drift or air return drift. Each confined work space will be equipped with an entrance airlock.

3.2.5 Earthquake

Disposal cell plugs are designed to be earthquake resistant, such that the containment envelope formed by the disposal cells remains under control post-earthquake.

APPENDICES

Appendices to VOLUME I Context – The Project – Safety Strategy

Appendix 1: List of regulatory texts and guides

Subject	Text	Reference
General Nuclear	French Environmental Code - Legislative Part Book I: Common Provisions Title II: Information and participation of citizens Chapter V: Other modes of information - Section 1: Provisions relative to activities other than nuclear activities (L 125 and following)	(41)
General Nuclear	French Environment Code - Legislative Part Book V: Prevention of pollution, risks and nuisances Title IV: Waste Chapter II: Specific provisions relating to the sustainable management of radioactive materials and waste (L 542 and following)	(42)
General Nuclear	French Environment Code - Legislative Part Book V: Prevention of pollution, risks and nuisances Title IX: Nuclear security and basic nuclear installations - Chapter I: General provisions relative to nuclear security (L 591 and following)	(43)
General Nuclear	French Environment Code - Legislative Part Book V: Prevention of pollution, risks and nuisances Title IX: Nuclear security and basic nuclear installations - Chapter III: Basic nuclear installations (L 593 and following).	(44)
General Nuclear	Decree No.2007-1557 relative to basic nuclear installations and to the control, in the nuclear safety field, of the transport of radioactive substances	(45)
General Nuclear	Order of 7 February 2012 setting out the general rules relative to basic nuclear installations	(16)
General Nuclear	Order of 11 January 2016 approving ASN Resolution 2015-DC-0532 of 17 November 2015 relative to the safety analysis report for basic nuclear installations	(46)
Impact on health and the environment	Order of 9 August 2013 approving ASN Resolution 2013-DC-0360 relative to management of pollution and the impact on health and the environment at basic nuclear installations	(47)
Impact on health and the environment	Order of 1 July 2015 approving ASN Resolution 2015-DC-0508 of 21 April 2015 relative to the study on waste management and the statement of waste produced at basic nuclear installations	(48)
Internal risks	Order of 20 March 2014 approving ASN Resolution 2014-DC-0417 of 28 January 2014 relative to the rules applicable to basic nuclear installations (INB) regarding management of fire risks	(32)
Internal risks	Order of 20 November 2014 approving ASN Resolution 2014-DC-0462 of 7 October 2014 relative to managing criticality risk at basic nuclear installations	(49)
Protection from ionising radiation	Directive 2013/59/Euratom laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom	(50)
Protection from ionising radiation	French Public Health Code - Regulatory Part - Part I: General health protection Book III: Protection of health and the environment Title III: Prevention of health risks related to the environment and to the workplace Chapter III: Ionising radiation – R1333-8/10	(25)

Subject	Text	Reference
Protection from ionising radiation	French Labour Code - Regulatory Part - Part IV: Health and Safety in the workplace Book IV: Preventing certain risks of exposure Title V: Preventing the risk of exposure to radiation Chapter I: Preventing the risk of exposure to ionising radiation (R 4451.1 and following)	(51)
Protection from ionising radiation	Order of May 15, 2006 relative to the conditions for demarcation and signposting of monitored and controlled areas and specially regulated or prohibited zones where there is a risk of exposure to ionising radiation, together with the applicable rules regarding health, safety and maintenance	(52)
Protection from ionising radiation	Order of 1 September 2003 defining the methods used to calculate effective doses and equivalent doses to people as a result of exposure to ionising radiation	(53)
General Environment	French Environment Code Regulatory Part Book I: Common Provisions Title II: Information and participation of citizens Chapter II: Environmental assessment (R 121-1 and following)	(54)
General Environment	French Environment Code Regulatory Part Book II: Physical environments Title I: Water and aquatic and marine environments Chapter IV: Activities, installations and use Section 1: Authorisation or declaration policies (R214-1: installations, structures, works and activities)	(55)
External risks	Order of 29 September 2005 relative to the evaluation and integration of the probability of occurrence, the kinetics, the intensity of the effects and the severity of the consequences of potential accidents in the hazard studies of classified installations subject to licensing	(24)
Prevention of occupational risks	French Labour Code - Legislative Part - Part IV: Health and Safety in the workplace Book I: General Provisions Title II: General principles relative to prevention (L 4121-1 and following)	(56)
Prevention of occupational risks	French Labour Code - Legislative Part - Part IV: Health and Safety in the workplace Book V: Prevention of risks related to specific activities and operations Title III: Building and Civil Engineering (L4531-1 and following)	(57)
Prevention of occupational risks	French Labour Code - Regulatory Part - Part IV: Health and Safety in the workplace Book II: Provisions applicable to the workplace Title I: The project owner's obligations regarding workplace design -	(58)
Prevention of occupational risks	French Labour Code - Regulatory Part - Part IV: Health and Safety in the workplace Book V: Prevention of risks related to specific activities and operations Title III: Building and Civil Engineering Chapter II: Coordination during building and civil engineering operations (R4532-1 and following) *(Transposition of Decree 94-1159 of 26 December 1994 relative to integrating safety and organising coordination in the field of health safety and protection during building and civil engineering operations)*	(57)
Prevention of occupational risks	French Labour Code - Regulatory Part - Part IV: Health and Safety in the workplace Book V: Prevention of risks related to specific activities and operations Title I: Work carried out at a site by an external firm (R4511-1 and following) *(Transposition of Decree 992-158 of 20 February 1992 supplementing the Labour Code and setting out the specific health and safety requirements applicable to work carried out at a site by an external firm)*	(59)

Subject	Text	Reference
Physical protection Tracking nuclear materials	Order of 20 November 2009 approving ASN Resolution 2009-DC-0153 of 18 August 2009 relative to intervention levels in the event of radiological emergency situations	(60)
Physical protection Tracking nuclear materials	Order of 9 June 2011 stipulating the conditions for implementing physical tracking and accountancy of nuclear materials the possession of which requires a license	(61)
Physical protection Tracking nuclear materials	Order of 10 June 2011 relative to the physical protection of facilities where nuclear materials is kept and the possession of which requires a license	(37)
Physical protection Tracking nuclear materials	Order of 3 August 2011 relative to the procedures for conducting the study provided for under Article R.1333-4 of the French Defence Code for the protection of nuclear materials	(62)
Physical protection Tracking nuclear materials	Order of 5 August 2011 relative to licence application procedures and to the form of the license required under Article L.1333-2 of the French Defence Code	(63)
Physical protection Tracking nuclear materials	Order of 23 July 2010 approving the general interministerial instruction on the protection of national defence secrets	(64)
Physical protection Tracking nuclear materials	Order of 30 November 2011 approving general interministerial instruction No.1300 on the protection of national defence secrets	(65)

Draft regulatory texts taken into consideration

Title of draft text	Part(s)/phase(s) of life of the installation in question	Reference
Draft Resolution relative to the safety analysis report for basic nuclear installations	Operating phase	(46)
Draft Resolution relative to the obligations of basic nuclear installation operators regarding preparedness for and management of emergency situations and to the content of the on-site emergency plan	Operating phase	(66)
Radioactive waste conditioning with a view to disposal and regarding the conditions for accepting radioactive waste packages at disposal facilities which are basic nuclear installations	Resolution focused on waste packages Implications for control procedures at surface facilities	(67)
Draft Resolution relative to waste disposal INBs	The parts and the phases covered will be specified according to the scope of application of the resolution (scheduled for 2016)	(46)

Guides and Basic Safety Rules (BSRs)

Risk	Title of BSR/Guide	Reference	Applicability to Cigeo			
			Surface	(Surface-to-bottom) connections	Connecting drifts	Disposal cells
	Safety guide for the final disposal of radioactive waste in a deep geological formation, 12 February 2008 *ASN Guide published on 12 February 2008*	(17)	A	A	A	A
	Guide No. 9 published on 31 October 2013 Determining the scope of an INB	(68)	A	A	A	A
External risks related to human activities	Aircraft crash *(BSR I.1.a 7 October 1992)* See note	(69)	A	R	NR	NR
	Industrial environment and means of access *(BSR I.1.b 7 October 1992*)	(70)	A	R	NR	NR
External risks related to the natural environment	Earthquakes *(BSG 2001-01, ASN Guide No. 2/01, Guide on Earthquakes, 30 May 2006)*	(71)	A	R	R	R
	External flooding *(ASN Guide No.13 published on 8 January 2013)*	(72)	A	R	NR	NR
Internal risks	Criticality *(BSR 1.3.c published on 18 October 1984)*	(73)	A	A	A	A
	Fire *(Guide on Fire, published May 2006)*	(74)	A	NA	NA	NA
Design	Ventilation systems design *(BSR II.2 published on 20 December 1991)*	(75)	A	NA	NA	A

A: applicable NA: non applicable R: pris en référence SO: sans objet

Appendix 2: Andra Reference documents

Subject	Title	Reference
Safety	Référentiel de sûreté appliqué à la conception de Cigéo pour la phase d'exploitation (Safety standards applied to Cigeo design for the operating phase)	(22)
Public/environmental impact	Démarche de choix et de description d'une ou plusieurs biosphère(s) (Approach used to choose and describe one or more biosphere(s))	(76)
	Valeurs toxicologiques de référence (VTR) retenues par l'Andra pour les toxiques chimiques pris en compte par l'Andra dans ses évaluations d'impact (Toxicity reference values (TRV) used by Andra for the toxic elements assessed by Andra in its impact assessments)	(77)
	Méthodologie pour la conception et le dimensionnement des moyens de protection (Methodology used in the conceptual and structural design of protective systems)	(78)
Scenarios	Démarche et critères de sélection des scénarios de sûreté en exploitation pour le projet Cigéo (Approach to and criteria to be used in the selection of safety scenarios during operating for the Cigeo Project)	(79)
Fire	Référentiel incendie pour la conception de l'installation souterraine de Cigéo (Fire safety standards for the design of the Cigeo underground facility)	(31)
Ventilation	Guide Ventilation Nucléaire - Méthodologie pour la conception et le dimensionnement des systèmes de ventilation nucléaire (Guidelines on Nuclear Ventilation Systems - Methodology used in the conceptual and structural design of nuclear ventilation systems)	(80)
Ramp transfer system	Référentiel technique applicable à la conception, la réalisation et l'exploitation d'un système de transfert incliné de colis de déchets radioactifs (Technical standards applicable to the design, construction and operating of a ramp transfer system for the transfer of radioactive waste packages)	(81)

Appendix 3: International texts

International standards

Source	Date published	Reference	Title
WENRA	2014	(82)	Radioactive waste disposal facilities Safety reference levels
IAEA	2006	(83)	SF-1 Fundamental Safety Principles
	2011	(84)	SSR-5 Disposal of Radioactive Waste
	2006	(85)	GS-R-3 The management system for Facilities and Activities
	2009	(86)	GSR Part 4 on the safety assessment for installations and activities
	2009	(51)	GSG-1 Classification of radioactive waste

International good practices

Source	Date published	Reference	Title
IAEA	2008	(87)	GS-G-3.4 The Management System for the Disposal of Radioactive Waste
	2011	(88)	SSG-14 Geological Disposal Facilities for Radioactive Waste
	2014	(89)	SSG-31 Monitoring and Surveillance of Radioactive Waste Disposal Facilities
	2012	(90)	SSG-23 The Safety Case and Safety Assessment for the Disposal of Radioactive Waste
	1996	(91)	INSAG-10: Defence in Depth in Nuclear Safety
	1991	(92)	INSAG-4: Safety Culture

ICRP

Source	Date published	Reference	Title
ICRP	2013	(93)	ICRP 122 Radiological Protection in Geological Disposal of Long-lived Solid Radioactive Waste
	2007	(94)	ICRP 103 The 2007 Recommendations of the International Commission on Radiological Protection

Appendix 4: Sources and texts applicable in the field of SOHF and ergonomics

The following sources, which publish recommendations and practical guides in the field of Social, Organisational and Human Factors (SOHF) and ergonomics, have been consulted:

- French National Agency for the Improvement of Working Conditions (ANACT): www.anact.fr
- French National Institute for Occupational Health and Safety Research (INRS): www.inrs.fr
- AFNOR for regulations and standards: www.afnor.org
- United States Nuclear Regulatory Commission (U.S. NRC) with regard to NUREG standards: www.nrc.gov
- International Atomic Energy Agency (IAEA): (https://www.iaea.org/) and, more specifically, certain reports by the International Safety Advisory Group (INSAG)

The following documents are referred to as applicable to Cigeo – known as core standards as they do not include the regulatory documents to which we have referred, mainly in relation to HSE:

Source	Text	Reference
International Atomic Energy Agency (IAEA)/INSAG	International Safety Advisory Group (INSAG) reports Nos. 3, 4, 10, 13, 15, 18 and 19 relating to safety culture, design, defence in depth and change management in the nuclear industry.	(91)
United States Nuclear Regulatory Commission - U.S. NRC	NUREG 0711 (November 2012) - Human Factors Engineering Program Review Model - Revision 3	(95)
ISO/AFNOR	NF EN ISO 6385 Août 2004 - Principes ergonomiques de la conception des systèmes de travail	(96)
ISO/AFNOR	NF EN ISO 11064 - Conception ergonomique des centres de commande	(97)
ISO/AFNOR	NF EN ISO 9241 - Ergonomie de l'interaction homme-système - Partie 210 : conception centrée sur l'opérateur humain pour les systèmes interactifs	(98)
ISO/AFNOR	NF EN ISO 9241-11 Juin 1998 - Exigences ergonomiques pour travail de bureau avec terminaux à écrans de visualisation (TEV) - Partie 11 : lignes directrices concernant l'utilisabilité	(99)
ISO/AFNOR	NF EN ISO 26800 Octobre 2011 - Ergonomie - Approche générale, principes et concepts	(100)
ISO/AFNOR	NF EN ISO 10075 - Principes ergonomiques concernant la charge de travail mental	(101)
AFNOR	NF X35-115 Avril 2009 - Ergonomie - Processus de conception centré sur l'opérateur humain	(102)
AFNOR	X60-301 Mai 1982 - Guide pour la prise en compte des critères de maintenabilité des biens durables à usage industriel et professionnel	(103)
AFNOR	X60-310 Novembre 1986 - Guide de maintenabilité de matériel - Première partie : sections un, deux et trois - Introduction, exigences et programme de maintenabilité	(104)
AFNOR	NF EN 60706-2 Septembre 2006 - Maintenabilité de matériel	(105)
INRS	ED 950 – 2011 - Conception des lieux et des situations de travail	
INRS	ED 773 – 2011 - Conception des lieux de travail – Obligations du maître d'ouvrage, réglementation	(106)

Source	Text	Reference
INRS	ED 79 – 1999 - Conception et aménagement des postes de travail - Fiche pratique de sécurité	(107)

Appendices to VOLUME II Presentation of the packages, the facility and its environment

Appendix 5: Summary of ILW-LL waste package families

Note: The last column in the tables below gives the production status:

- [T] for waste package families for which production is finished;
- [EC] for waste package families currently being produced;
- [F] for waste package families for which production has not yet begun;
- [AD] for waste package families for which the conditioning is still at the research stage.

Cigeo ILW-LL waste families for which production is finished

Type ID	Type title	Identifier 2012 Edition of the IN	Primary container	Number of packages	Production status
CEA-070	500-litre concrete containers containing drums of filtration sludge embedded in a cementitious material, produced in accordance with a quality assurance specification	F2-5-02	500 l concrete	43	T
CEA-080	870-litre carbon steel containers produced from 1972 to 1990 containing miscellaneous waste in a cement-bitumen matrix	F2-5-04	870 l	2,188	T
CEA-090	870-litre non-alloy steel containers produced from 1990 to the end of 1993 containing miscellaneous waste (mainly alpha Pu) immobilised in a cementitious material	F2-5-04	870 l	562	T
CEA-100	870-litre non-alloy steel containers containing 700-litre drums of 800 g/l concentrates embedded in a cementitious material	F2-5-03	870 l	40	T
CEA-110	500-litre carbon steel containers produced from 1970 to 1990 containing miscellaneous waste in a cement-bitumen matrix	F2-5-05	500 l steel	427	T
CEA-120	500-litre non-alloy steel containers produced from 1990 to 1994 containing miscellaneous waste immobilised in a cementitious material	F2-5-05	500 l steel	210	T
CEA-140	500-litre concrete containers produced before 1994 containing drums of filtration sludge embedded in a cementitious material	F2-5-02	500 l concrete	2,297	T
CEA-150	500-litre concrete containers containing drums of evaporation concentrates embedded in a cementitious material	F2-5-02	500 l concrete	381	T
CEA-231	Drums of radium-bearing lead sulphates from the Le Bouchet plant conditioned in 5 m³ concrete containers	F2-5-01	5 m3 concrete	19	T
CEA-280	223-litre non-alloy steel drums containing filtration sludge embedded in a cementitious material (including drums produced in accordance with a quality assurance specification)	F2-5-02	Steel drum	2,149	T
CEA-290	Non-alloy steel containers from the reconditioning of 1800-litre concrete containers containing miscellaneous waste immobilised in a cementitious material	F2-5-06	Steel container	169	T
CEA-300	Non-alloy steel containers from the reconditioning of 1800-litre concrete containers containing miscellaneous waste immobilised in a cement-bitumen matrix	F2-5-06	Steel container	11	T
CEA-310	Non-alloy steel containers produced from the reconditioning of 1000-litre concrete containers containing miscellaneous waste immobilised in a cement-bitumen matrix or a sludge/cement mixture	F2-5-06	Steel container	88	T
CEA-320	Steel drums containing sludges or concentrates or a mixture of cemented sludges and concentrates	F2-6-02	Steel drum	360	T
CEA-330	870-litre non-alloy steel containers containing metal and organic waste from "Pegase"	F2-5-04	870 l 313 Fl	619	T
CEA-450	Non-alloy steel containers from the reconditioning of concrete containers known as "source assemblies"	F2-9-01	Steel container	41	T
CEA-1010	Stainless steel overdrums containing non-alloy steel drums of bituminised waste produced in accordance with a quality assurance specification (from 1995 to 1996)	F2-4-03	EIP	1,709	T
CEA-1020	Stainless steel overdrums containing non-alloy steel drums of bituminised waste produced before 1995, transported in primary packages	F2-4-04	EIP	12,955	T
CEA-1021	Stainless steel overdrums containing non-alloy steel drums of bituminised waste produced before 1995, transported in disposal packages	F2-4-04	EIP	11,467	T
CEA-1120	AVM-type stainless steel containers containing vitrified waste from Marcoule UP1 washwater effluents (ILW-LL glass packages)	F2-4-13	AVM container	147	T
CEA-1180	200-litre alpha drums stored in building 99 in the north sector of CDS, to be placed temporarily in a 500-litre reversible hull	DIV 2	Steel drum	183	T
COG-040	Drums of cemented hulls and nozzles produced in accordance with the specification 300 AQ 025	F2-3-01	Steel drum	1,517	T
COG-050	Packages of cemented solid operating waste produced before 1994 in accordance with the specification 300 AQ 038	F2-3-07	CAC	324	T
COG-420	Drums of bituminised STE2 waste (partial recovery from silo 550-14)	F2-3-05	Steel drum	340	T

Cigeo ILW-LL waste package families for which production is in progress

Cigeo ILW-LL waste package families which have not yet been produced and for which the definition of the waste conditioning is already well advanced

Type ID	Type title	Identifier 2012 Edition of the IN	Primary container	Number of packages	Production status
CEA-050	870-litre non-alloy steel containers produced in accordance with a quality assurance specification (from 01/01/94) containing miscellaneous waste (mainly alpha Pu) immobilised in a cementitious material	F2-5-04	870 l	3,550	EC
CEA-060	500-litre steel containers produced since 1994 in accordance with a quality assurance specification, containing miscellaneous waste immobilised in a cementitious material	F2-5-05	500 l steel	1,250	EC
CEA-480	Non-standard pre-grouted 223-litre packages	DIV 2	Steel drum	50	EC
CEA-1000	Stainless steel overdrums containing stainless steel drums of bituminised waste produced in accordance with a quality assurance specification (from October 1996)	F2-4-03	EIP	2,700	EC
CEA-1100	870-litre non-alloy steel containers containing metal and organic technological waste immobilised in a cementitious material (alpha waste from Marcoule)	F2-5-04	870 l FI	410	EC
COG-020	Drums of bituminised STE3 waste produced in accordance with the specification 300 AQ 027	F2-3-04	Steel drum	11,900	EC
COG-030	Packages of cemented solid operating waste produced after 1994 in accordance with specification 300 AQ 044	F2-3-08	CBF-C'2	8,292	EC
COG-100	Standard canisters for compacted waste/CSD-C produced in accordance with the specification 300 AQ 055 (including hulls and nozzles from ECE drums and from pools S1, S2 and S3)	F2-3-02	CSD-C	6,675	EC
COG-110	Standard canisters for compacted waste (CSD-C) containing hulls and nozzles from UOX fuel assemblies	F2-3-02	CSD-C	17,850	EC
COG-470	CSD-B packages containing vitrified medium-level effluents (final shutdown of UP2-400, UP2-800 and UP3)	F2-3-11	CSD-B	900	EC

Cigeo ILW-LL waste package families which have not yet been produced and for which the conditioning is still at the research stage

Type ID	Type title	Identifier 2012 Edition of the IN	Primary container	Number of packages	Production status
AND-000	Waste collected by Andra conditioned in 870-litre containers	S01	870 l	19	AD
CEA-360	Waste from the dismantling of Phenix core objects	F2-4-12	To be defined	781	AD
CEA-370	Exotic objects from Phenix	F2-4-12	To be defined	8	AD
CEA-380	Miscellaneous waste containing B4C from the operation and dismantling phases of the Rapsodie and Phenix FNR reactors	F2-4-15	To be defined	3	AD
CEA-400	Irradiating waste from the dismantling of Rapsodie, cleanup of the pits at Cadarache and the operation and dismantling of the JHR	-	To be defined	200	AD
CEA-410	Irradiating waste from the operation and dismantling of various facilities at Saclay	-	To be defined	300	AD
CEA-420	Waste from the operation and dismantling of various facilities at Fontenay-aux-Roses	-	To be defined	230	AD
CEA-430	Miscellaneous waste from the operation, cleanup and dismantling phases of various facilities at the Grenoble Centre	DIV 2	To be defined	40	AD
CEA-460	Waste from the dismantling of CEA's Valduc facilities	-	870 l	40	AD
CEA-1040	Stainless steel drums containing cemented process wastes	F2-4-10	EIP	3,013	AD
CEA-1050	Stainless steel drums containing cemented metal structural waste (including from the dismantling of the Celestin reactors)	F2-4-07	EIP	1,320	AD
CEA-1060	Stainless steel drums containing magnesium structural waste immobilised in a cementitious material	F2-4-09	Steel drum	7,464	AD
CEA-1090	Stainless steel drums containing metal and organic technological waste immobilised in a cementitious material	F2-4-11	EIP	1,353	AD
CEA-1110	Technological waste from AVM	F2-4-05	To be defined	188	AD
CEA-1140	Stainless steel drums containing cemented filtration sludge from the Stema facility	F2-4-10	EIP	120	AD
CEA-1151	Structural waste, miscellaneous metal waste and waste from the dismantling of the TOP and TOR lines, to be reconditioned in EIP drums	F2-4-14	EIP	60	AD
CEA-1152	Structural waste, miscellaneous metal waste and waste from the dismantling of the TOP and TOR lines	F2-4-14	To be defined	450	AD
CEA-1200	Miscellaneous waste stored in buildings 211 and 213 (excluding containers of Piver vitrified waste and other HLW glass packages)	DIV 2	To be defined	50	AD
EDF-100	Activated dismantling waste from PWRs in the current fleet (including BCOT)	-	To be defined	6,360	AD
EDF-110	PWR primary and secondary source rods and other miscellaneous sealed sources	S01	To be defined	20	AD
EDF-120	Waste from AMI at Chinon	DIV 2	To be defined	100	AD
EDF-250	Miscellaneous waste containing B4C from the operation and dismantling phases of the Superphenix FNR reactor	F2-4-15	To be defined	5	AD

Appendix 6: Summary of the types of HLW waste packages

List of HLW waste package families under consideration for Cigeo

Type ID	Type title	Identifier 2012 Edition of the IN	Primary container	Number of packages	Production status
CEA-200	Piver containers produced between 1969 and 1981 and containing solutions of Sioral and Phénix fission products in a glass matrix	F1-5-01	Stainless steel canister containing 2 Piver containers	88	F
CEA-350	Stainless steel containers containing vitrified Atalante waste	-	AVM container	5	F
CEA-1070	Containers de vitrified AVM waste produced in accordance with a QA specification since March 1995	F1-4-01	AVM container	865	T
CEA-1080	Containers of vitrified AVM waste produced before 1995	F1-4-01	AVM container	2,294	T
CEA-1190	Miscellaneous vitrified waste (laboratory glassware) stored in APM building 213 (excluding Piver)	F1-5-01	To be defined	8	AD
CEA-1500	HLW radioactive sources (137Cs, 90Sr, 238Pu)	S01	AVM container	7	F
COG-140	Standard vitrified waste containers/CSD-V: UOX glass produced according to specification 300 AQ 016	F1-3-01	CSD-V	6,900	T
COG-150	Standard vitrified waste containers/CSD-U: UMo glass produced according to specification 300 AQ 059	F1-3-02	CSD-U	1,000	EC
COG-200	Standard vitrified waste containers/CSD-V: UOX/URE/MOX glass	F1-3-01	CSD-V	24,060	F
COG-800	Standard vitrified waste containers/CSD-V: UOX glass produced according to specification 300 AQ 060	F1-3-01	CSD-V	19,010	EC
COG-810	Standard vitrified waste containers/CSD-V: R7/T7 purge glass	F1-3-01	CSD-V	250	EC
COG-820	Standard vitrified waste containers/CSD-V: calcine glass	F1-3-01	CSD-V	75	EC
COG-830	Standard vitrified waste containers/CSD-V: REP/RNR glass (Superphénix and Phénix)	F1-3-01	CSD-V	1,095	F
COG-850	Technological waste from vitrification facilities and conditioned in standard containers	F1-3-03	CSD	200	F
COG-860	Waste from ELAN IIB elution columns conditioned into standard containers	F1-3-05	CSD	52	F
COG-870	Strontium titanate capsules conditioned in standard containers	F1-3-04	CSD	3	F
COG-880	Packages of vitrified waste from CEA/Civil SF reprocessing	F1-3-01	CSD-V	11	F
COG-890	Packages of vitrified waste from CEA/DAM SF reprocessing	F1-3-01	CSD-V	80	F
COG-900	Packages of vitrified waste from EL4 reprocessing	F1-3-01	CSD-V	30	F

Appendix 7: ILW-LL co-disposal

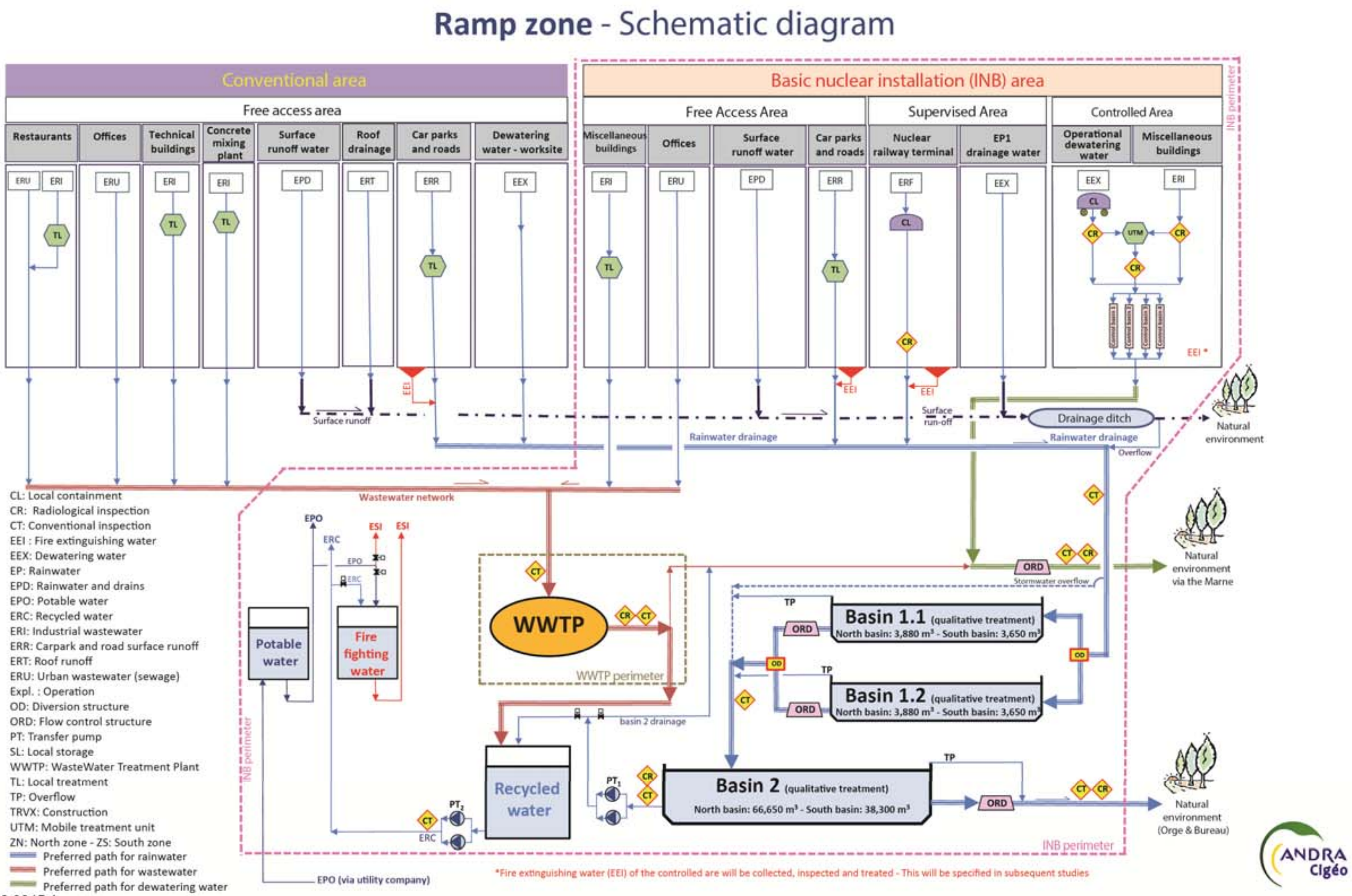
Elementary family ID	Elementary family title	Category
CEA-070	500-litre concrete containers containing drums of filtration sludge embedded in a cementitious material, produced in accordance with a quality assurance specification	ILW-LL1
CEA-100	870-litre non-alloy steel containers containing 700-litre drums of 800 g/l concentrates embedded in a cementitious material	ILW-LL1
CEA-140	500-litre concrete containers produced before 1994 containing drums of filtration sludge embedded in a cementitious material	ILW-LL1
CEA-150	500-litre concrete containers containing drums of evaporation concentrates embedded in a cementitious material	ILW-LL1
CEA-231	Drums of radium-bearing lead sulfates from the Le Bouchet plant conditioned in 5 m³ concrete containers	ILW-LL1
CEA-232	Drums of radium-bearing lead sulfates from the Le Bouchet plant conditioned in EIP containers	ILW-LL1
CEA-280	223-litre non-alloy steel drums containing filtration sludge embedded in a cementitious material (including drums produced in accordance with a quality assurance specification)	ILW-LL1
CEA-310	Non-alloy steel containers produced from the reconditioning of 1000-litre concrete containers containing miscellaneous waste immobilised in a cement-bitumen matrix or a sludge/cement mixture	ILW-LL1
CEA-320	Steel drums containing sludges or concentrates or a mixture of cemented sludges and concentrates	ILW-LL1
CEA-1140	Stainless steel drums containing cemented filtration sludge from the STEMA facility	ILW-LL1
COG-430	Dried STE2 sludge, compacted and immobilised in a metal container	ILW-LL1
CEA-1000	Stainless steel overdrums containing stainless steel drums of bituminised waste produced in accordance with a quality assurance specification (from October 1996)	ILW-LL2
CEA-1010	Stainless steel overdrums containing non-alloy steel drums of bituminised waste produced in accordance with a quality assurance specification (from 1995 to 1996)	ILW-LL2
CEA-1020	Stainless steel overdrums containing non-alloy steel drums of bituminised waste produced before 1995, transported in primary packages	ILW-LL2
CEA-1021	Stainless steel overdrums containing non-alloy steel drums of bituminised waste produced before 1995, transported in disposal packages	ILW-LL2
COG-020	Drums of bituminised STE3 waste produced in accordance with the specification 300 AQ 027	ILW-LL2
COG-420	Drums of bituminised STE2 waste (partial recovery from silo 550-14)	ILW-LL2
CEA-370	Exotic objects from Phenix	ILW-LL3
CEA-420	Waste from the operation and dismantling of various facilities at Fontenay-aux-Roses	ILW-LL3
CEA-1040	Stainless steel drums containing cemented process wastes	ILW-LL3
COG-040	Drums of cemented hulls and nozzles produced in accordance with the specification 300 AQ 025	ILW-LL3
COG-070	Standard canisters for compacted waste (CSD-C) containing hulls and nozzles from the high activity oxide (HAO) silo	ILW-LL3
COG-440	Cemented ECE drum containing fines and resins from the HAO silo	ILW-LL3
AND-000	Waste collected by Andra conditioned in 870-litre containers (used sealed sources, etc.)	ILW-LL3
CEA-050	870-litre non-alloy steel containers produced in accordance with a quality assurance specification (from 01/01/94) containing miscellaneous waste (mainly alpha Pu) immobilised in a cementitious material	ILW-LL3
CEA-060	500-litre steel containers produced since 1994 in accordance with a quality assurance specification, containing miscellaneous waste immobilised in a cementitious material	ILW-LL3
CEA-080	870-litre non-alloy steel containers produced from 1972 to 1990 containing miscellaneous waste immobilised in a cement-bitumen matrix	ILW-LL3
CEA-090	870-litre non-alloy steel containers produced from 1990 to the end of 1993 containing miscellaneous waste (mainly alpha Pu) immobilised in a cementitious	ILW-LL3

Elementary family ID	Elementary family title	Category
	material	
CEA-110	500-litre non-alloy steel containers produced from 1970 to 1990 containing miscellaneous waste immobilised in a cement-bitumen matrix	ILW-LL3
CEA-120	500-litre non-alloy steel containers produced from 1990 to 1994 containing miscellaneous waste immobilised in a cementitious material	ILW-LL3
CEA-270	870-litre non-alloy steel containers containing miscellaneous waste immobilised in a cementitious material (CEA/DAM Valduc)	ILW-LL3
CEA-290	Non-alloy steel containers from the reconditioning of 1800-litre concrete containers containing miscellaneous waste immobilised in a cementitious material	ILW-LL3
CEA-300	Non-alloy steel containers from the reconditioning of 1800-litre concrete containers containing miscellaneous waste immobilised in a cement-bitumen matrix	ILW-LL3
CEA-330	870-litre non-alloy steel containers containing metal and organic waste from "Pegase"	ILW-LL3
CEA-400	Irradiating waste from the dismantling of Rapsodie, the cleanup of the pits at Cadarache and the operation and dismantling of the JHR	ILW-LL3
CEA-410	Irradiating waste from the operation and dismantling of various facilities at Saclay	ILW-LL3
CEA-440	500-litre stainless steel containers containing miscellaneous non-compactable waste immobilised in a cementitious material (operation of CABRI, dismantling of Rapsodie, pits at CAD, CENG)	ILW-LL3
CEA-450	Non-alloy steel containers from the reconditioning of concrete containers known as "source assemblies"	ILW-LL3
CEA-460	Waste from the dismantling of facilities at the CEA Valduc centre	ILW-LL3
CEA-480	Non-standard pre-concreted 223-litre packages	ILW-LL3
CEA-1090	Stainless steel drums containing metal and organic technological waste immobilised in a cementitious material	ILW-LL3
CEA-1100	870-litre non-alloy steel containers containing metal and organic technological waste immobilised in a cementitious material (alpha waste from Marcoule)	ILW-LL3
CEA-1110	Technological waste from AVM	ILW-LL3
CEA-1151	Structural waste, miscellaneous metal waste and waste from the dismantling of the TOP and TOR lines, to be reconditioned in EIP drums	ILW-LL3
CEA-1152	Structural waste, miscellaneous metal waste and waste from the dismantling of the TOP and TOR lines	ILW-LL3
CEA-1180	200-litre alpha drums stored in building 99 in the north sector of CDS, to be placed temporarily in a 500-litre reversible hull	ILW-LL3
CEA-1510	Radioactive sources (alpha, neutron and other)	ILW-LL3
COG-030	Packages of cemented solid operating waste produced after 1994 in accordance with the specification 300 AQ 044	ILW-LL3
COG-050	Packages of cemented solid operating waste produced before 1994 in accordance with the specification 300 AQ 038	ILW-LL3
COG-400[84]	Alpha waste from Melox and LHA	ILW-LL3
COG-460	Standard canisters for compacted waste (CSD-C) containing metal and organic technological waste and dismantling waste	ILW-LL3
COG-480	CBF-C'2 containers containing operating and dismantling waste (ATTILA pit bins)	ILW-LL3
COG-490	Waste from end-of-operation and dismantling operations at the UP2-400, UP2-800 and UP3 plants compacted in CSD-C canisters	ILW-LL3
COG-500	Waste from end-of-operation and dismantling operations at the UP2-400, UP2-800 and UP3 plants conditioned in CBF-C'2 containers	ILW-LL3
COG-510	Waste from end-of-operation and dismantling operations at the MELOX plant conditioned in CBF-C'2 containers	ILW-LL3
COG-520	Waste from end-of-operation and dismantling operations at the Cadarache CFCa facilities conditioned in CBF-C'2 containers	ILW-LL3

[84] This family could eventually be part of the ILW-LL6 category depending on its conditioning

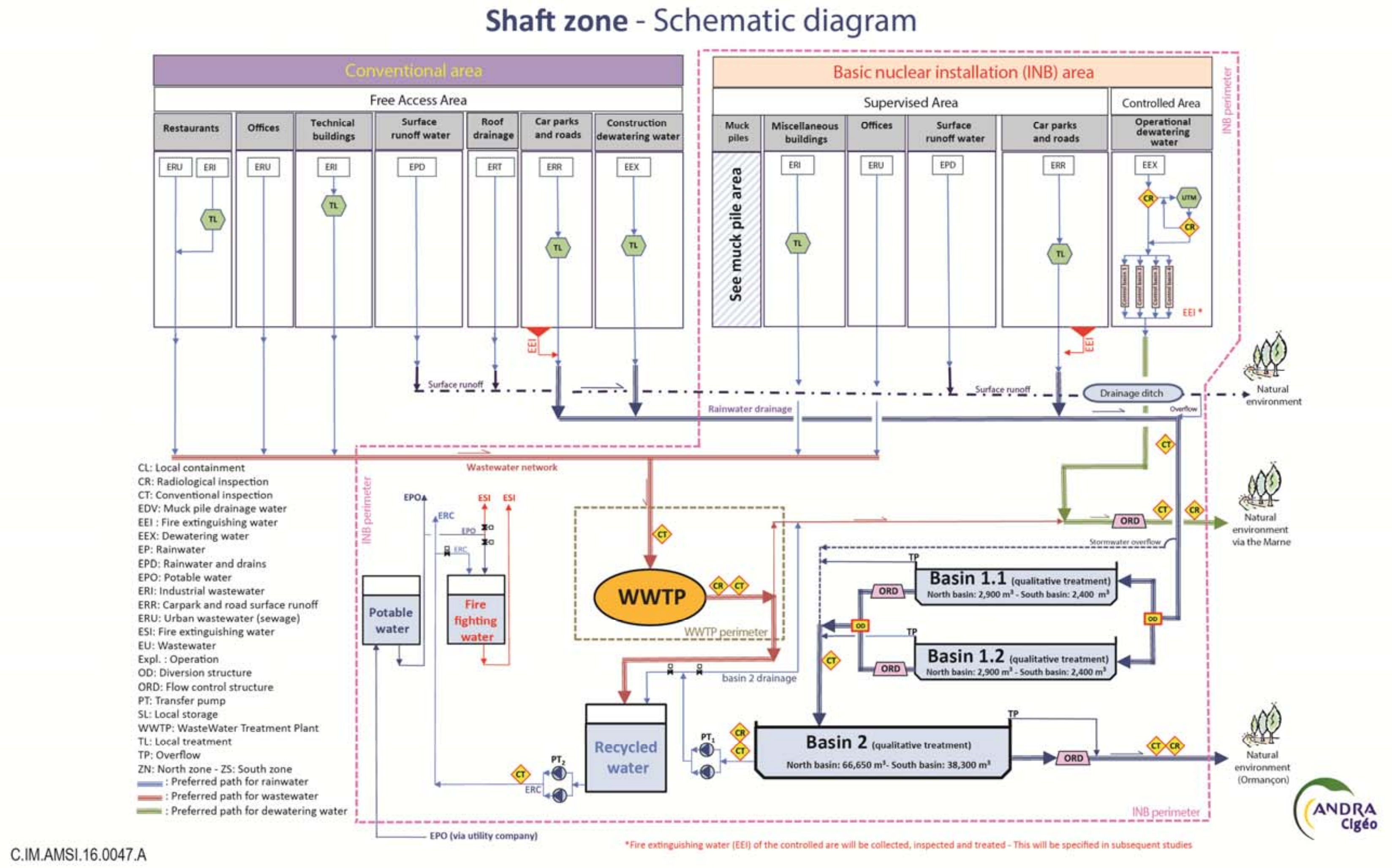
Elementary family ID	Elementary family title	Category
EDF-120	Waste from AMI at Chinon	ILW-LL3
CEA-1050	Stainless steel drums containing cemented metal structural waste (including from the dismantling of the Celestin reactors)	ILW-LL4
CEA-1060	Stainless steel drums containing magnesium structural waste immobilised in a cementitious material	ILW-LL4
EDF-080	C1PG containers of PWR activated operating waste	ILW-LL4
EDF-090	C1PG containers of first train activated dismantling waste excluding sodium-bearing waste from Superphenix	ILW-LL4
EDF-100	Activated dismantling waste from PWRs in the current fleet (including BCOT)	ILW-LL4
ITER-010	Miscellaneous waste produced during the operation, maintenance and dismantling phases of the ITER reactor	ILW-LL4
CEA-360	Waste from the dismantling of Phenix core objects	ILW-LL5
CEA-430	Miscellaneous waste from the operation, cleanup and dismantling phases of various facilities at the Grenoble Centre	ILW-LL5
CEA-1200	Miscellaneous waste stored in buildings 211 and 213 (excluding containers of PIVER vitrified waste and other HLW glass packages)	ILW-LL5
COG-100	Standard canisters for compacted waste/CSD-C produced in accordance with the specification 300 AQ 055 (including hulls and nozzles from ECE drums and from pools S1, S2 and S3)	ILW-LL5
COG-110	Standard canisters for compacted waste (CSD-C) containing hulls and nozzles from UOX fuel assemblies	ILW-LL5
COG-120	Standard canisters for compacted waste (CSD-C) containing hulls and nozzles from UOX/ERU/MOX fuel assemblies	ILW-LL5
COG-450	Standard canisters for compacted Waste (CSD-C) containing structural waste from PWR and FNR fuel assemblies (Superphenix and Phenix)	ILW-LL5
COG-550	Packages of compacted structural waste from EL4 SF reprocessing	ILW-LL5
EDF-110	PWR primary and secondary source rods and other miscellaneous sealed sources	ILW-LL5
COG-530	Packages of compacted structural waste from CEA/Civil SF reprocessing	ILW-LL5
COG-540	Packages of compacted structural waste from CEA/DAM SF reprocessing	ILW-LL5
CEA-340	Standard waste canister (CSD) containing vitrified americium-bearing effluents (Valduc ILW-LL glass packages)	ILW-LL6
CEA-1120	AVM-type stainless steel containers containing vitrified waste from Marcoule UP1 rinse effluents (ILW-LL glass packages)	ILW-LL6
COG-470	CSD-B packages containing vitrified medium-level effluents (final shutdown of UP2-400, UP2-800 and UP3)	ILW-LL6
CEA-380	Miscellaneous waste containing B4C from the operation and dismantling phases of the Rapsodie and Phenix FNR reactors	ILW-LL7
EDF-250	Miscellaneous waste containing B4C from the operation and dismantling phases of the Superphenix FNR reactor	ILW-LL7

Appendix 8: Schematic diagram of water management in the ramp zone

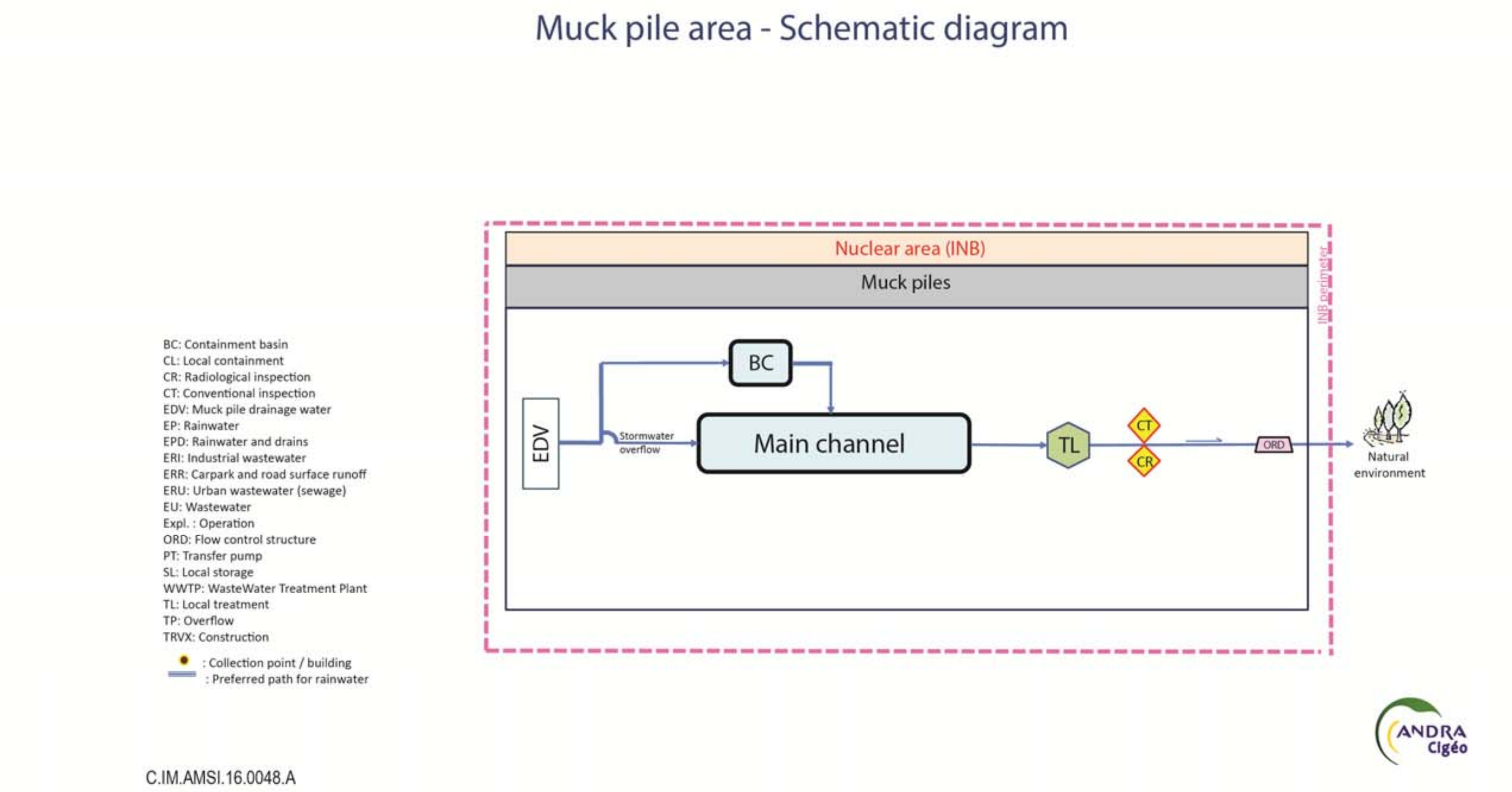


C.IM.AMSI.16.0045.A

Appendix 9: Schematic diagram of water management in the shaft zone

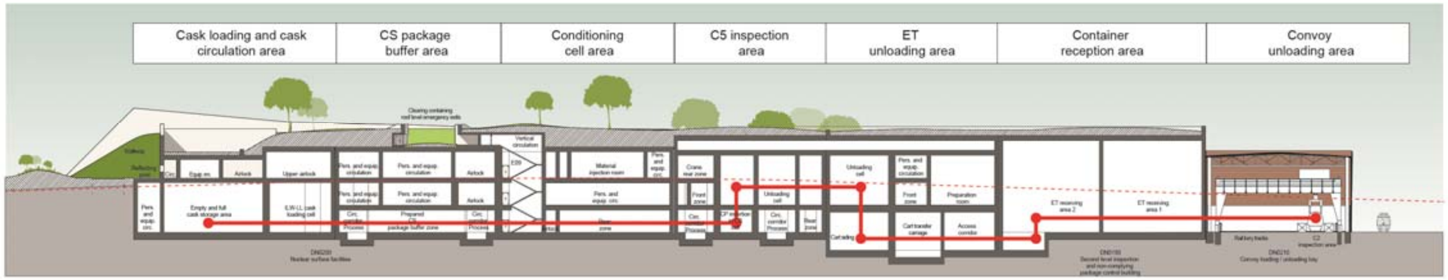


Appendix 10: Schematic diagram of water management in the shaft zone near the spoil piles



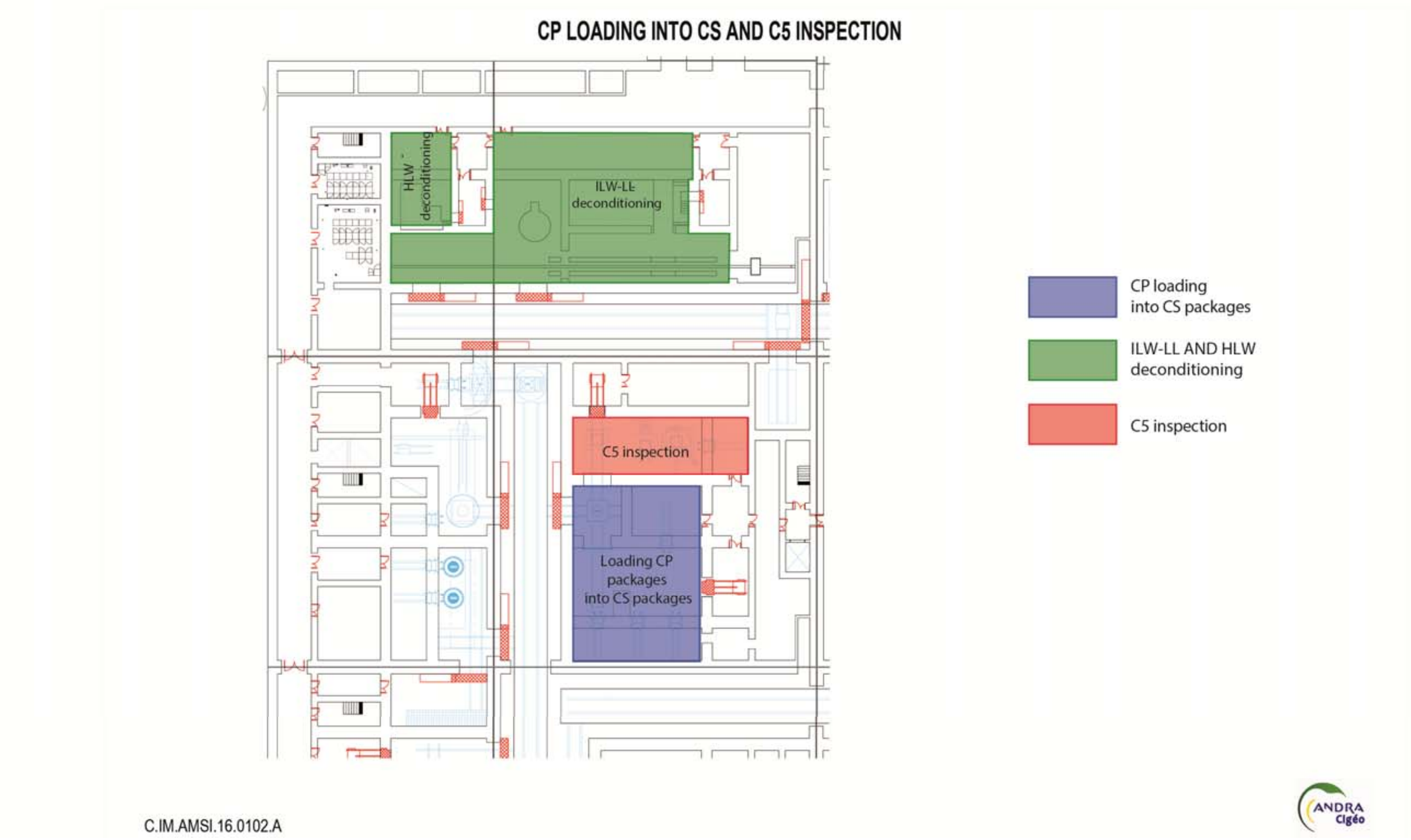
Appendix 11: Cross-sectional view of the EP1 facility

Cross-sectional view of main process

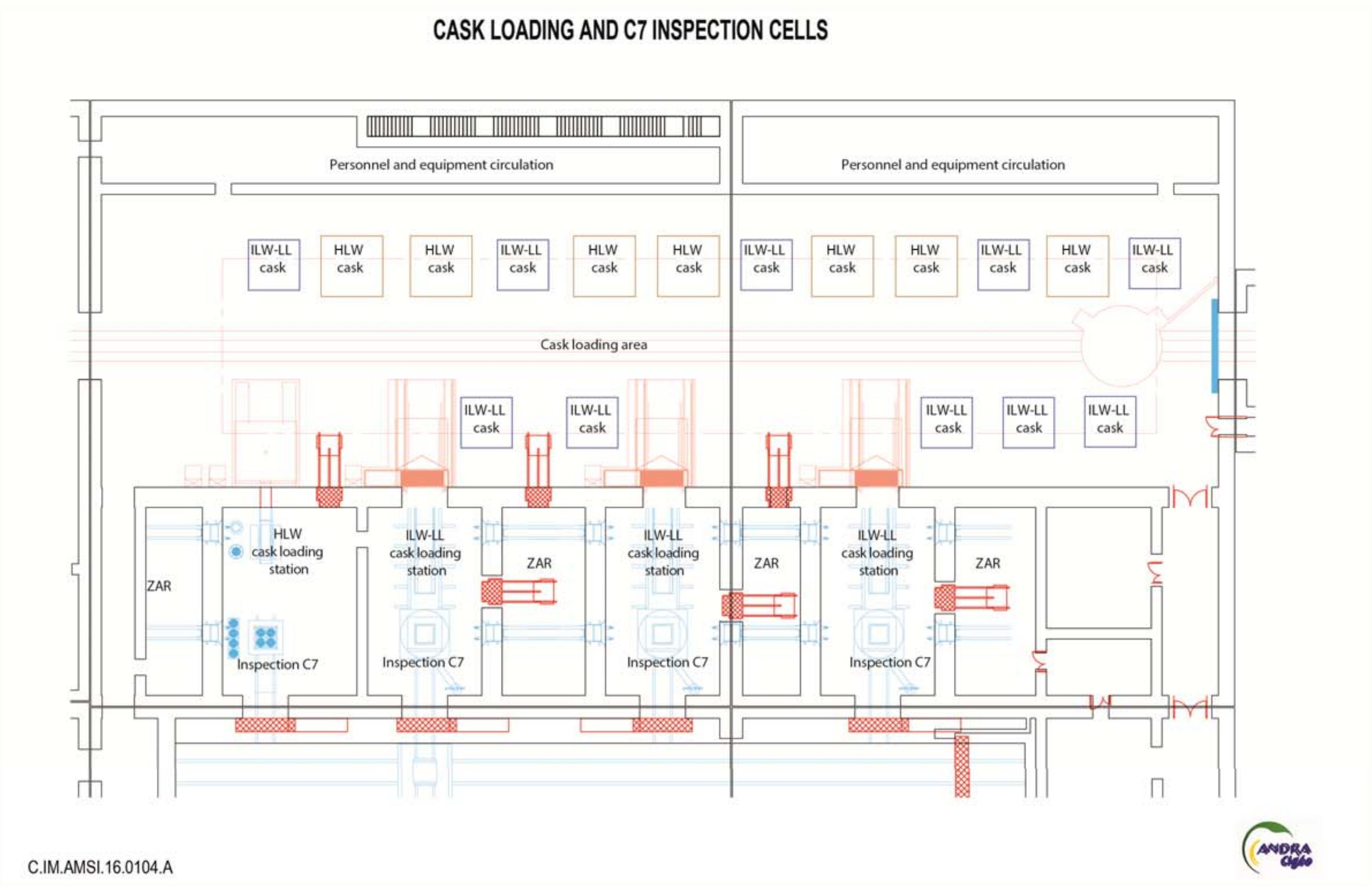


C.IM.0EKS.15.0025.A

Appendix 12: Cell for C5 control and loading of primary packages into secondary packages (illustration at end of APS)



Appendix 13: Cell for C7 control and HLW and ILW-LL cask loading (illustration at end of APS)

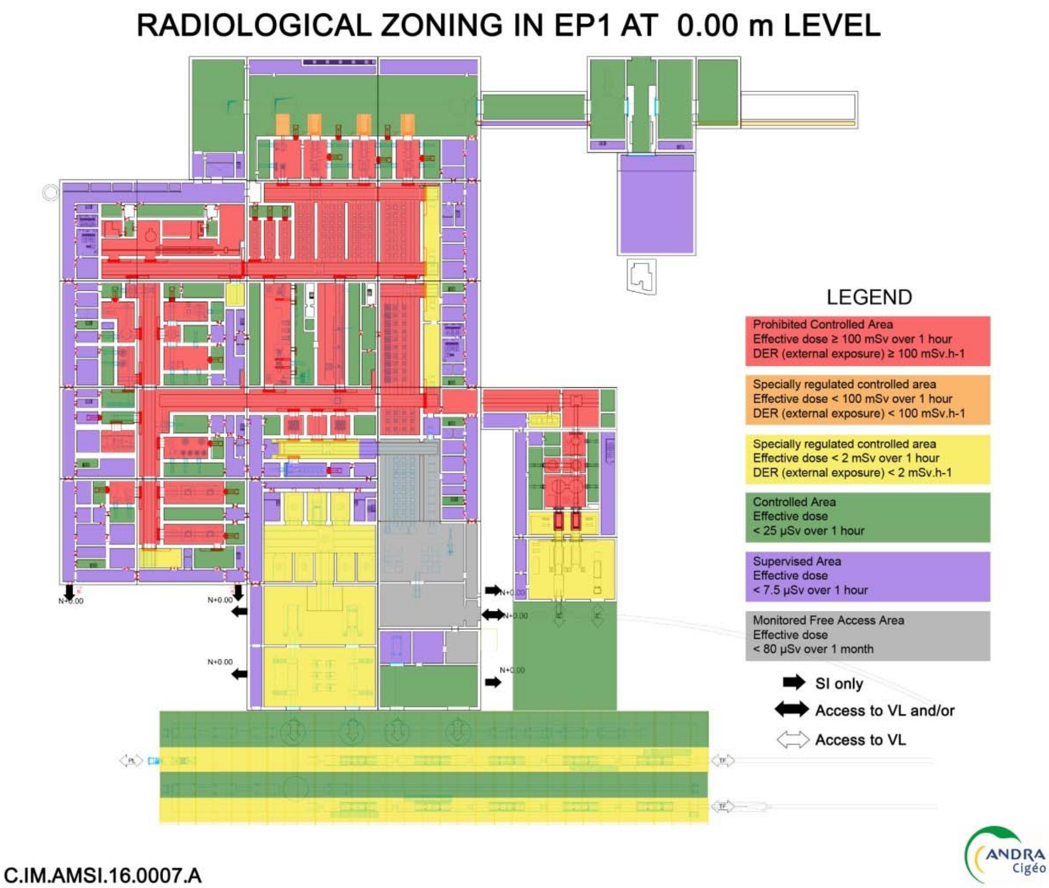


Appendices to VOLUME III Safety Options Relating to Waste Package Transfer and Emplacement Operations

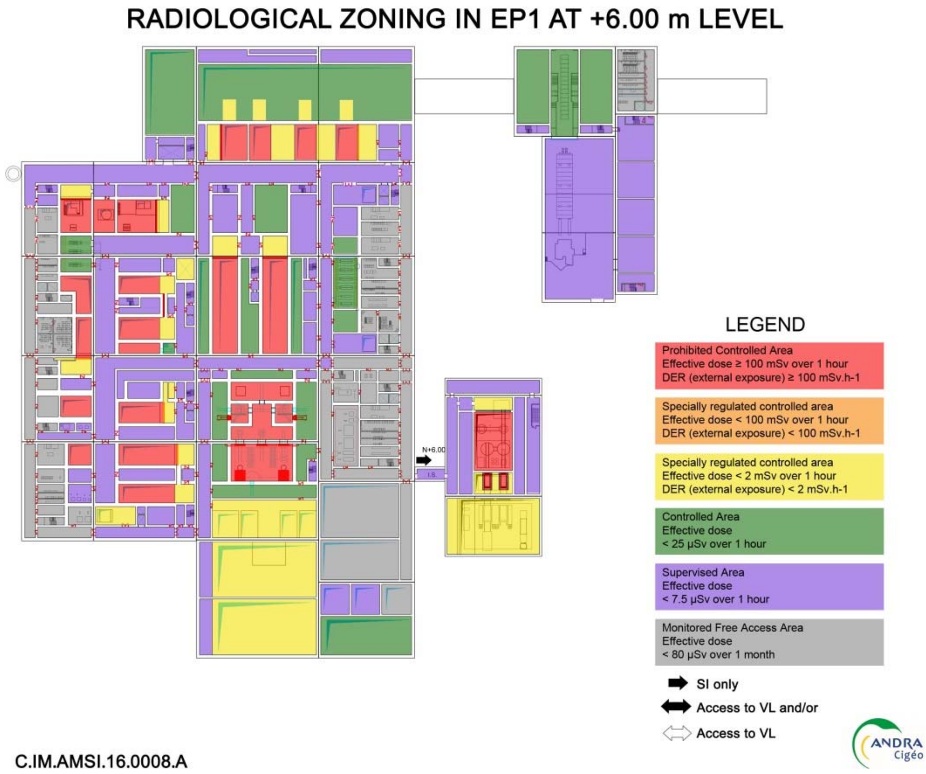
Appendix 14: Assumption on resuspension ratios in the event of a fall

	Matrix		
Primary container	No matrix or matrix unknown	Bitumen	Cement
Steel	1E-04	1E-06	1E-05
Stainless steel with welded lid	1E-05		1E-06
Concrete container	1E-04		1E-05
Unknown	1E-03		1E-04

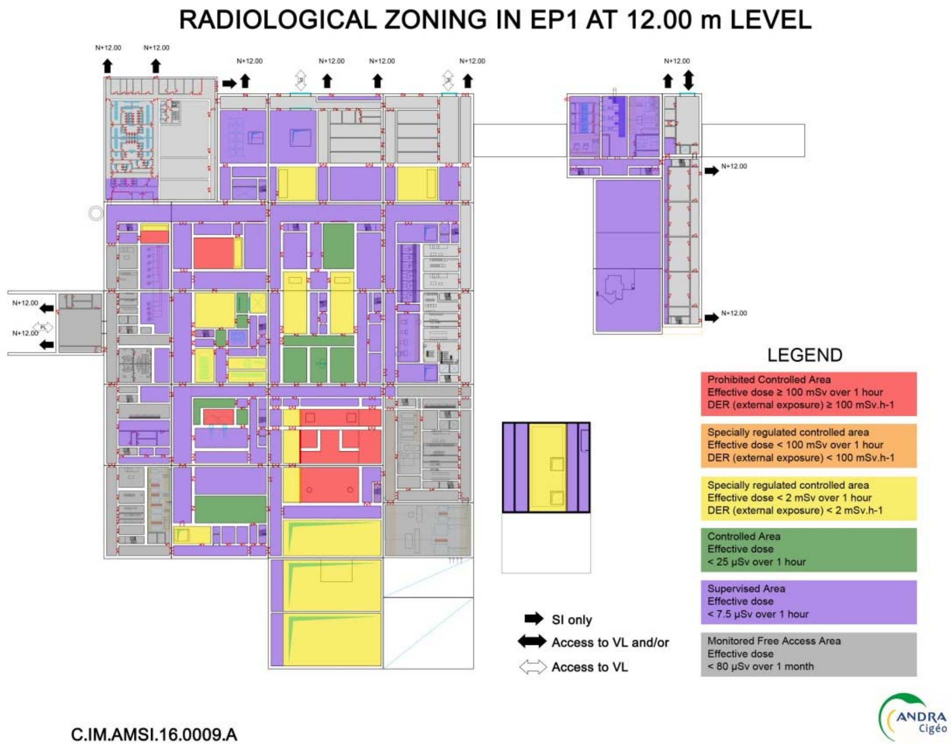
Appendix 15: Radiological zoning in EP1at elevation 0.00 m



Appendix 16: Radiological zoning in EP1at elevation 6.00m



Appendix 17: Radiological zoning in EP1at elevation 12.00m



Appendix 18: Assumptions on resuspension fractions of surface contamination in the event of fire

Non-combustible medium	Suspended fraction
Volatile or semi-volatile elements (^{3}H, ^{14}C, caesium)	1
Non-volatile elements (cobalt and other commonly found elements)	5.00E-02
Alpha emitters	5.00E-03

Appendix 19: Assumptions on resuspension fractions of package activity in the event of fire

RN	Coeff.	RN	Coeff.	RN	Coeff.	RN	Coeff.	RN	Coeff.	RN	Coeff.
^{3}H	5.00E-01	^{85}Kr	5.00E-01	^{126}Sn	4.00E-03	^{153}Gd	1.00E-03	^{208}Bi	4.00E-03	^{241}Pu	1.00E-03
^{10}Be	3.00E-02	^{87}Rb	2.00E-01	^{125}Sb	4.00E-03	^{157}Tb	1.00E-03	^{210m}Bi	4.00E-03	^{242}Pu	1.00E-03
^{14}C	6.00E-03	^{90}Sr	3.00E-02	^{129}I	5.00E-02	^{158}Tb	1.00E-03	^{208}Po	4.00E-03	^{244}Pu	1.00E-03
^{22}Na	2.00E-01	^{90}Y	1.00E-03	^{134}Cs	2.00E-01	^{154}Dy	0	^{209}Po	4.00E-03	^{241}Am	1.00E-03
^{26}Al	1.00E-03	^{93}Zr	1.00E-03	^{135}Cs	2.00E-01	^{163}Ho	1.00E-03	^{226}Ra	3.00E-02	^{242m}Am	1.00E-03
^{32}Si	6.00E-03	^{91}Nb	3.00E-02	^{137}Cs	2.00E-01	^{166m}Ho	1.00E-03	^{228}Ra	3.00E-02	^{243}Am	1.00E-03
^{36}Cl	5.00E-02	^{92}Nb	3.00E-02	^{137m}Ba	3.00E-02	^{171}Tm	1.00E-03	^{227}Ac	1.00E-03	^{242}Cm	1.00E-03
^{39}Ar	5.00E-01	^{93m}Nb	3.00E-02	^{133}Ba	3.00E-02	^{173}Lu	1.00E-03	^{228}Th	1.00E-03	^{243}Cm	1.00E-03
^{42}Ar	5.00E-01	^{94}Nb	3.00E-02	^{137}La	1.00E-03	^{174}Lu	1.00E-03	^{229}Th	1.00E-03	^{244}Cm	1.00E-03
^{40}K	2.00E-01	^{93}Mo	3.00E-02	^{144}Ce	1.00E-03	^{176}Lu	1.00E-03	^{230}Th	1.00E-03	^{245}Cm	1.00E-03
^{41}Ca	3.00E-02	^{97}Tc	3.00E-02	^{144}Pr	1.00E-03	^{172}Hf	1.00E-03	^{232}Th	1.00E-03	^{246}Cm	1.00E-03
^{44}Ti	4.00E-03	^{98}Tc	3.00E-02	^{143}Pm	1.00E-03	^{178n}Hf	1.00E-03	^{231}Pa	1.00E-03	^{247}Cm	1.00E-03
^{49}V	3.00E-02	^{99}Tc	3.00E-02	^{144}Pm	1.00E-03	^{182}Hf	1.00E-03	^{232}U	1.00E-03	^{248}Cm	1.00E-03
^{53}Mn	3.00E-02	^{106}Ru	2.00E-03	^{145}Pm	1.00E-03	^{179}Ta	3.00E-02	^{233}U	1.00E-03	^{250}Cm	1.00E-03
^{54}Mn	3.00E-02	^{106}Rh	2.00E-03	^{146}Pm	1.00E-03	^{186m}Re	3.00E-02	^{234}U	1.00E-03	^{247}Bk	1.00E-03
^{55}Fe	3.00E-02	^{101}Rh	2.00E-03	^{147}Pm	1.00E-03	^{194}Os	0	^{235}U	1.00E-03	^{249}Bk	1.00E-03
^{60}Fe	3.00E-02	^{102}Rh	2.00E-03	^{145}Sm	1.00E-03	^{192n}Ir	0	^{236}U	1.00E-03	^{248}Cf	1.00E-03
^{57}Co	3.00E-02	^{102m}Rh	2.00E-03	^{146}Sm	1.00E-03	^{193}Pt	2.00E-03	^{238}U	1.00E-03	^{249}Cf	1.00E-03
^{60}Co	3.00E-02	^{107}Pd	4.00E-03	^{151}Sm	1.00E-03	^{195}Au	0	^{235}Np	1.00E-03	^{250}Cf	1.00E-03
^{59}Ni	2.00E-03	^{108m}Ag	4.00E-03	^{150}Eu	1.00E-03	^{194}Hg	0	^{236}Np	1.00E-03	^{251}Cf	1.00E-03
^{63}Ni	2.00E-03	^{110m}Ag	4.00E-03	^{152}Eu	1.00E-03	^{204}Tl	4.00E-03	^{237}Np	1.00E-03	^{252}Cf	1.00E-03
^{Zn}65	4.00E-03	^{109}Cd	4.00E-03	^{154}Eu	1.00E-03	^{202}Pb	4.00E-03	^{236}Pu	1.00E-03	^{252}Es	1.00E-03
^{68}Ge	0	^{113m}Cd	4.00E-03	^{155}Eu	1.00E-03	^{205}Pb	4.00E-03	^{238}Pu	1.00E-03	^{254}Es	1.00E-03
^{79}Se	7.00E-02	^{119m}Sn	4.00E-03	^{148}Gd	1.00E-03	^{210}Pb	4.00E-03	^{239}Pu	1.00E-03		
^{81}Kr	5.00E-01	^{121m}Sn	4.00E-03	^{150}Gd	1.00E-03	^{207}Bi	4.00E-03	^{240}Pu	1.00E-03		

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