OPERATIONAL SAFETY AND RADIOPROTECTION CONSIDERATIONS WHEN DESIGNING THE ILW-LL DISPOSAL ZONE

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Abstract

Operational safety and radioprotection requirements within the disposal cell have driven the design at the 2005 feasibility stage of the Andra programme in the framework of the French Act of 1991. Preliminary risk analysis focused on the four major hazards that determine the design: first, the external exposure risk by irradiation (and also internal exposure by inhalation) and then hazards due to accidental conditions, such as a waste package drop in the disposal drift, explosion due to potential hydrogen accumulation, and fire breaking out in the underground installations. Some key design features and orientations have been developped to meet safety requirements. The various reviews of the Andra "dossier argile" that was published in 2005 and the existing design experience has helped to identify the key areas needing further development and design evolution in order to apply for a license to build a repository in 2015 according to the new French Act of 2006.

1 Introduction

The December 30, 1991 French Waste Act entrusted Andra, the French national agency for radioactive waste management, with the task of assessing the feasibility of deep geological disposal of High Level and Long-lived waste (HLLLW). The emphasis placed on the demonstration of safety [1] was gradually combined with considerations regarding prudent repository management. As a result, two guiding principles – long term safety and retrievability – are fundamental requirements inherent in Andra's repository design concept. Of course, other concerns, such as the safety of workers and the protection of the public and the environment during the operation of the facility, are also essential in the design of the facility. The long term safety requirements have been set by the regulatory body RFS, 1991) and have helped in the design option selection and scientific studies since the 1991 French Act.

The "Dossier 2005 Argile" (Andra, 2005) presents the feasibility assessment within a step by step decision making process that was built upon an iterative approach between site characterization, design, modelling, and safety analysis, in which two principles always guided the elaboration of the safety case (i) Robustness – repository components must meet safety requirements and maintain their functionality given reasonable solicitations, taking into account events and uncertainties on the nature and level of these solicitations; (ii) Demonstrability – the safety must be verifiable without requiring complex demonstrations, but based on multiple lines of evidence/argument (numerical simulation, qualitative arguments such as use of natural analogues, experiments and technological demonstrators).

Although the safety approach of the Dossier 2005 goes back to the concepts and the general spirit of a "conventional " nuclear installation safety approach, it differs from such an approach in a few general aspects notably: (i) the necessity of approaching in a coordinated way the different life phases of the repository (i.e. operation, and post-closure) ; (ii) the timescales which extend beyond human experience; (iii) the strong relationship between technical design, scientific knowledge acquisition and safety assessments; and (iv) a unique activity mixing mining and nuclear operations. In this context, the integration of the scientific knowledge and the definition of a clear safety approach are key elements in the development of a coherent safety case. Andra has developped a safety approach that consists of implementing two complementary safety approaches according the repository phases. The first one concerns the operating safety, which is close to a conventional approach supported by a risk analysis. The other one concerns assessment of the long term safety in the post-closure phase in order to evaluate the repository robustness. The design options presented hereafter are a result of the feedback of the application of those two safety approaches

The present paper describes the integrated design approach with its application for ILW-LL disposal drifts, as shown in the Dossier 2005 report and focuses on the operational phase.

2 Presentation of the French ILW-LL 2005 Design

The French design results from an iterative process that starts with the basic input data and ends by designing a “solution” and assessing its safety, with repeated feedback exchanged between the various processes (see **Figure 1**). Three main iteration loops have been identified since 1991, each corresponding to a major milestone of the design program.

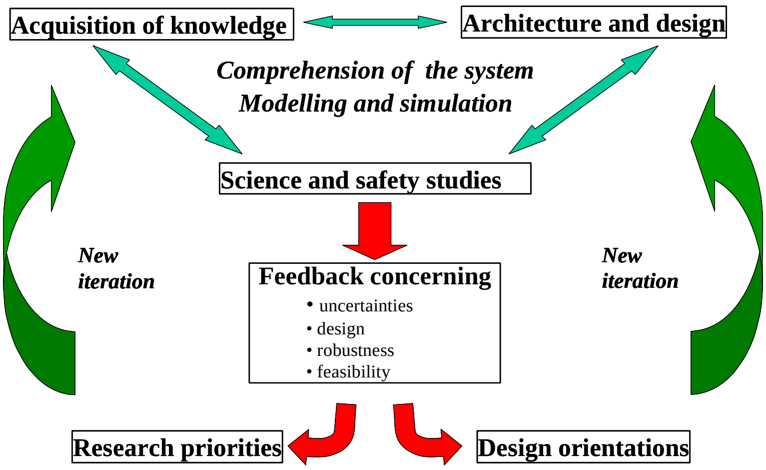


Figure 1 : Dossier 2005 Argile; three iterations loops since 1991 (1996, 2001, 2005)

2.1 French ILW-LL waste inventory

The French ILW-LL waste inventory to be disposed of constitutes basic input data for the feasibility study of ILW disposal and includes future, but already identified waste that has yet to be produced by the current French nuclear power plant fleet. The underlying design options and the feasibility assessment are thus based upon knowledge of such an inventory. Quantity, type and characteristics of current and future waste packages including their behaviour in a repository environment (during operational and post closure phases) and potential radionuclide release (e.g. gas) are a key input when establishing a design and the related transfer processes. The waste inventory includes mainly operating waste from nuclear power plants, waste from spent fuel reprocessing activities at La Hague and Marcoule (such as hulls and end-pieces), and waste produced within research and industrial CEA facilities.

The waste inventory represents around 200,000 primary packages with a total volume of 80,000 m^3. Given their diverse origins and the history of the facilities producing them, there is a large variety of waste, conditioning process, and primary package characteristics (mass, geometry, irradiation). Some wastes, such as bituminous waste, include organic materials and release small amounts of hydrogen by radiolysis. By way of example, the primary packages vary in diameter and length from 0.4 m to 1.8 m and from 0.7 m to 1.7 m respectively. They weigh between 0.3 and 9 metric tons. Package materials are as diverse as carbon steel, stainless steel and concrete. Considering the diversity of primary waste, they are grouped into a limited number of representative waste packages. The selection of representative waste packages takes into account the relevant parameters for the deep repository studies in view of its feasibility (e.g. waste contents, conditioning process, geometry and mass).The following **Figure 2** shows examples of primary waste packages.

Figure 2: ILW-LL Stainless steel drums

2.2 ILW-LL waste disposal package design

ILW-LL primary waste packages vary tremendously in size, shape, characteristics and handling methods. Compactness, ease of handling and reversible repository management are objectives that resulted in a decision to place the primary packages inside appropriate overpacks in view of simplifying the operating processes in underground facilities.

The overpack technical solution presented in the Andra's "Dossier 2005" is a High Performance Concrete (HPC) parallelepiped container to be handled under radiological shielding. It can hold up to four primary waste packages per waste disposal package. The external geometry of the container is standardised according to a limited number of models. Its width and height are limited to 2.5 metres. Its length does not exceed 3 metres. It is stackable over several levels in the disposal cell. The HPC concrete also provides mechanical integrity for a period of at least one hundred years which is important with respect to potential waste package retrieval.

The standard container consists of a prefabricated body and lid (see **Figure 3**) made of lightly fibre-reinforced concrete with rebars. The container is closed by mechanically sealing the lid to the body using a hydraulic binder (mortar) poured into a groove between the body and the lid and securing the lid to the body by five anchor bolts. The waste disposal package comprises the container and the enclosed waste.

2.3 Facility layout and handling operations for ILW-LL disposal

The waste disposal package is planned to be manufactured, sealed, controlled and temporarily stored at a surface facility; thereafter transferred to the underground facility and disposed of in a disposal cell (see **Figure 4**). This paper focuses on the safety analysis regarding the ILW-LL transferring process from the surface to the disposal cell. Therefore, it presents hereafter the handling process and the underground layout devoted to the ILW-LL waste packages.

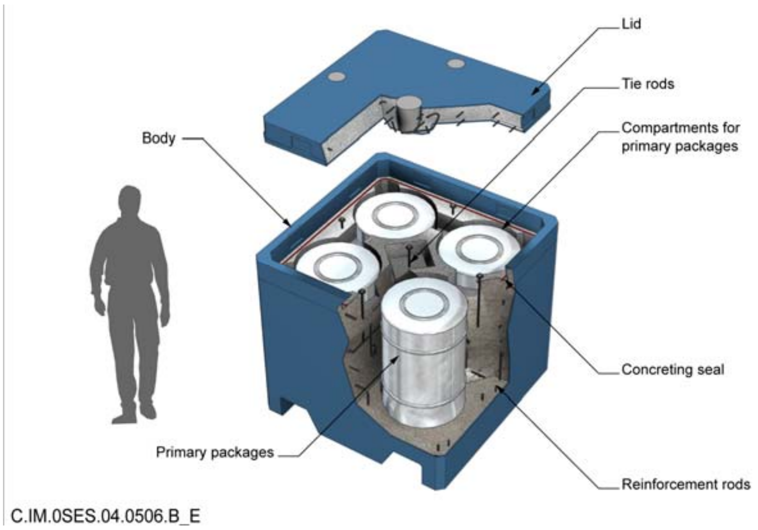


Figure 3: Standard waste disposal package

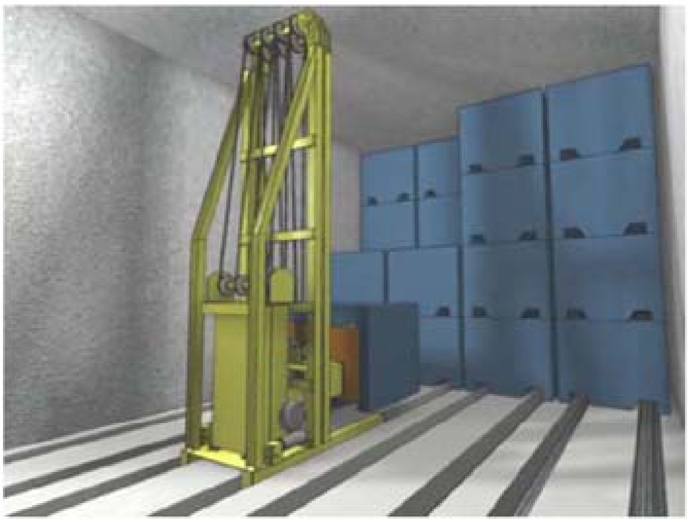


Figure 4*:* Final handling operations in the disposal cell

2.4 ILW-LL Handling process description (from surface to disposal cell)

The principle for transferring the disposal waste packages between the surface installations and the disposal cell depends mainly on radiological protection considerations. The equivalent dose rate around the disposal packages makes it impossible to handle them without providing radiological protection for the personnel. Therefore those disposal packages are put into a shielded so-called "radiological protection" transfer cask.

The cycle of transferring the protective transfer casks containing the disposal packages from the surface installations to the disposal cells consists of the four following stages (see **Figure 5**):

- on surface loading the transfer cask onto a transport vehicle;
- transferring the transfer cask to the repository disposal horizon either via a shaft or via a decline;

- transferring the transfer cask through the disposal horizon drifts, by a vehicle similar to the one used on surface;

- docking the transfer cask at the head of the disposal cell.

Eventually, in the irradiating disposal cell, the waste package[1] is handled by a remotely controlled self-propelled fork lift and stacked in its final emplacement location (see **Figure 6**).

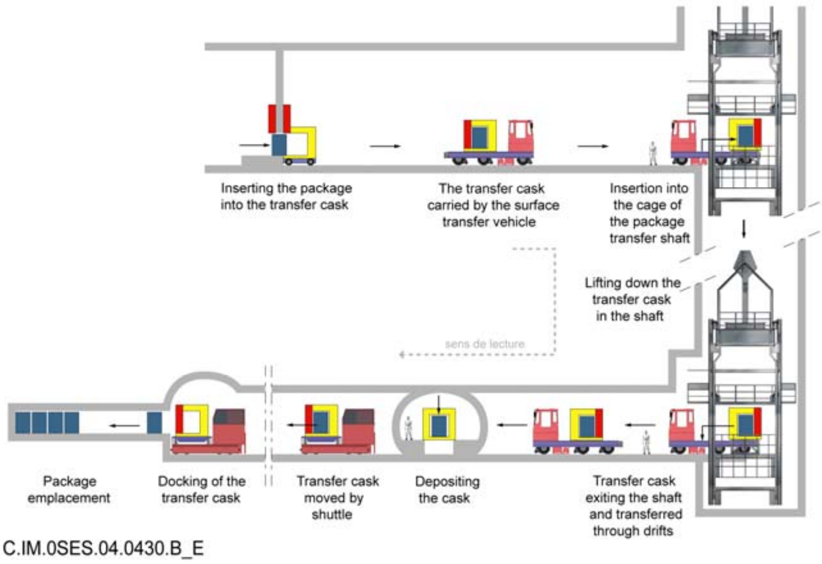


Figure 5 : Waste package transfer from surface to disposal drift

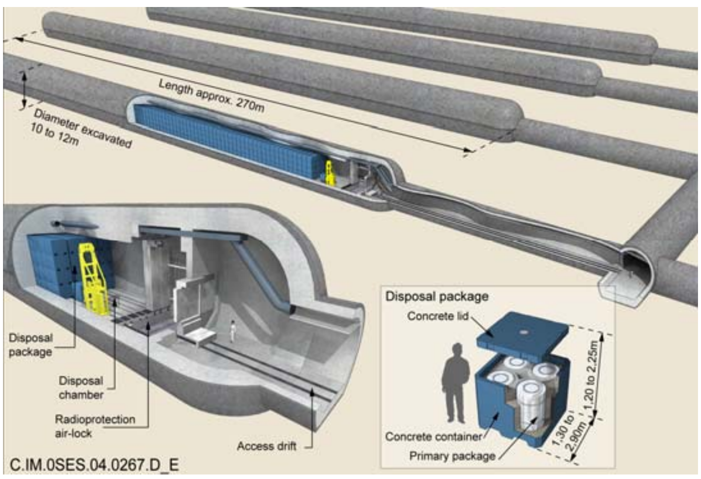


Figure 6: IL-LL waste disposal cell in operation

2.4.1 Underground ILW-LL disposal facility layout

As presented in the Dossier 2005, the general layout of the disposal facility includes the shaft, and an underground network of drifts and disposal cells. The ILW-LL disposal zone covers around 80 ha and is separated from the HLW zone. It is composed of a total of 38 disposal drifts (or cells). The long

[1] The package includes slots under the body for insertion of the fork

term analysis has resulted in isolating some specific waste drifts from others (e.g , for the organic waste – with hydrogen generation – drifts are separated from the other waste drifts in particular to avoid any chemical disturbance). Hence, in 2005 design, two specific subzones have been created. Organic waste is disposed of within 24 disposal cells, and the other waste in 14 disposal cells.

The ILW-LL disposal cell is linked to the connecting drift network via a small diameter access drift (this drift will be sealed when the cell is closed). This disposal cell (see **Figure 6**) is a sub-horizontal, dead-end tunnel, with a useful length of approximately 250 m and an excavated diameter of 10 to 12 m. The tunnel is concrete-lined. This disposal cell consists of an irradiating chamber in which the packages are disposed of using a remote-controlled fork lift truck. A radiation protection chamber which can house all the in-cell mechanical equipment is located in the head part of the disposal cell. The cell is ventilated throughout its needed period of operation in order to evacuate gases generated by the concerned wastes.

3 Risk Analysis Methodology and Interaction with Design Development

As mentioned in the Introduction, the design development is the result of an iterative approach. Given the need to verify, especially during the operational phase, that the design concept meets the safety/acceptability criteria (e.g dose criteria for the public and for workers), the following related steps are included in the iterative process (see **Figure 7**) are a:

- functional analysis (FA) to determine the safety functions and associated requirements;
- description of the repository and the associated transfer processes and the Phenomenological Analysis of Repository Situations (PARS) providing a scientific understanding of the evolution of the repository from surface and underground laboratory experiments;
- risk analysis (RA) to identify external and internal risks during the different phases of the installation (construction, operation and closure) and propose associated risk reduction measures;
- quantitative assessment [indicators] of selected scenarios including sensitivity cases to evaluate the impact.

To ensure that safety considerations govern repository design, as well as construction and operating processes, the safety functions mentioned below are used as a basis for developing technical requirements which are imposed on design options. In addition, requirements related to reversibility are also taken into account.

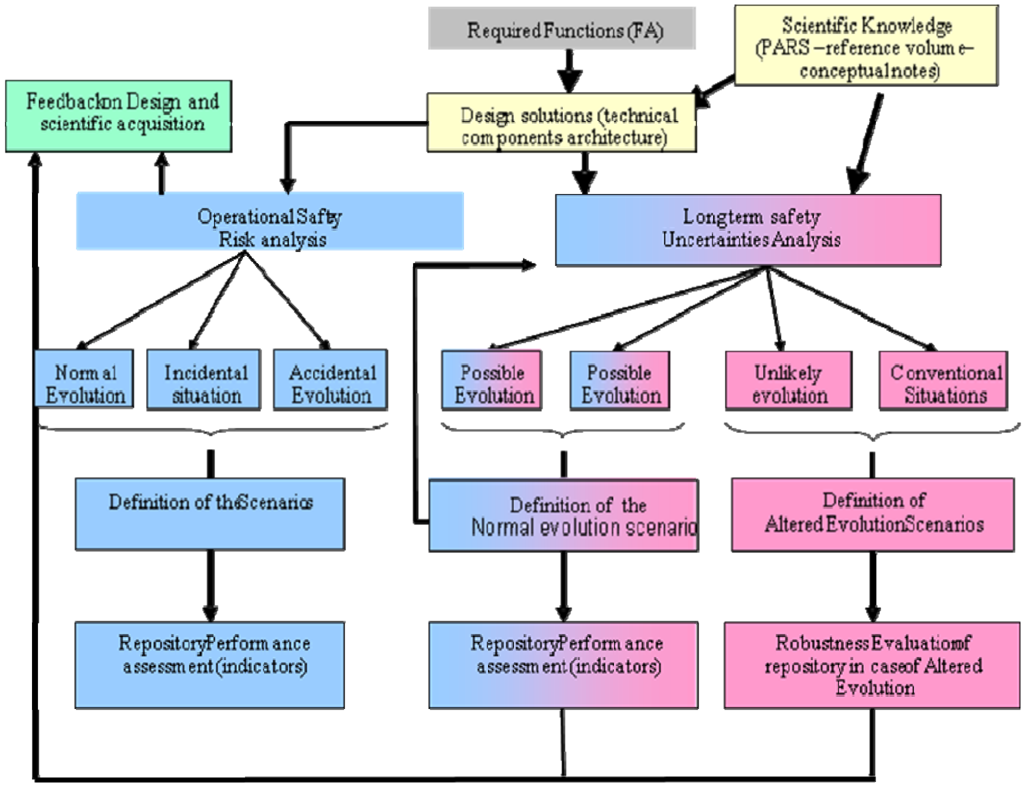


Figure 7: The iterative process illustrating links between risk analysis and long term safety and design options

3.1 The main safety functions

The repository's design follows a conventional approach: it consists of identifying those functions that need to be fulfilled by the installation and matching them to technical solutions while ensuring the radioprotection objective. During the operational period, the safety functions are mainly deduced from (i) the potential radioactive nuclides dispersal channels and (ii) principal hazards posed by radioactive waste that could affect the protection of humans and the environment. These have to be considered for all phases during which operators are liable to be present for the purpose of handling radioactive waste packages, for placing them in cells, for monitoring them, for maintenance as well as for removing them within the context of reversibility. For ILW-LL waste, these nuclear safety functions are similar to those considered in conventional basic nuclear installations. They are to:

- confine the radioactivity, so as to prevent the risk of radionuclide dispersal. This function also makes it possible to confine any chemical toxics that may be present;
- protect persons from radiation;
- provide criticality hazard safety;
- evacuate residual heat produced by the disposal packages;
- evacuate gases produced for example by radiolysis, in order to manage both the explosive hazards and their potential toxicity.

3.2 Risk analysis

The operation of transferring, handling and disposing of the disposal waste packages into the underground repository presents radiological risks to persons on account of the nature of the waste packages in particular the risk of external exposure (by irradiation) and the risk of internal exposure (by inhalation or ingestion). The purpose of the risk analysis is to enable steps to be taken (i) to prevent conventional risks pertaining to any industrial activity; (ii) to control all risks induced by radioactive-waste packages; and (iii) to take into account all risks involving the external environment of the repository. Those measures must also ensure Andra's radiation-protection objectives, which are an annual dose respectively below 5mSv/y for workers and individuals, and which are below 0,25 mSv/y for the public at the site boundaries. The risk analysis focuses on the specificities of the repository and does not aim at exhaustiveness, at the stage of the feasibility study. It is based on a classical methodology and begins by identifying internal and external sources of hazards that could occur at each step of the waste package transfer and which could affect the normal operation of the repository (from the surface to their disposal cell).

The risk analysis involves the following steps:

- inventory of hazard sources involving any product, equipment and process being used;
- qualitative characterization of risks (description, likelihood, severity, etc.);
- suggestion of risk-limiting measures such as preventive measures to prevent or minimise the occurrence of risk, as well as protective measures that are taken to rule out or mitigate the effects. Monitoring measures complete the risk reduction measures;
- identification of specific risks for which complementary studies have been carried out:
  - significant risks for the overall design of installations (fire, etc.);
  - inherent risks to the activity of the repository (drop or fire involving waste packages, etc.).

The risk analysis needs to be structured with ranking physical components (surface installations, access shafts, underground installations) and activities (construction, operation, closure) and in compliance with the defined operational safety functions.

The support of experts, the use of conventional tools and a "standard" list of hazards help in establishing a comprehensive and structured list of risks likely to be encountered by personnel and the environment (according to the stage of design development and the objective of the feasibility). The Experts in the different technical fields concerned (nuclear installations, shaft transfer equipment, underground tunnels, etc.) analyze the risks in bringing their expertises with comparable installations to bear. That enables a qualitative judgement to be made on the remaining degree of residual risk in spite of the risk reduction measures proposed. This expert appraisal is carried out as a function of the likelihood of the risk arising and the significance of its potential consequences for personnel, members of the public and the environment.

The existing risk analysis which is based on the current knowledge of the installations has highlighted the risks that require particular attention on account of their specific characteristics or their impact on the design of the repository and its equipment.

These risks are primarily the risk of explosion associated with the emission of gas from some waste packages, the risk of fire in underground installations focusing on accidental scenariis that would involve disposal packages and the risks associated with the transfer of packages of radioactive material and ILW-LL waste disposal packages accidentally falling in disposal cells. The subsequent section describes those above risks and their relationship with the design development.

4 Safety Analysis Related to the Major Risks

This analysis is focused on design measures, and underlines the relationship between design and safety analysis. The main internal risks, identified and associated with the disposal process, are presented by type of risk and by distinguishing between radiological risks that exist in normal conditions and accidental situations which may result in the release of nuclear materials (such as a fire or fall affecting waste disposal packages).

4.1 Radiological risk in normal conditions

The disposal waste package (primary waste container and overpack) is not designed to guarantee radiological protection with respect to external exposure to radiation. The equivalent dose flow rate goes up to 1,6 Sv/h at 1m distance for the type "B5" (hulls and end pieces) disposal package, and still amounts to 47 mSv/h for "B2" bitumen waste. Hence, the design has to provide for radiological shielding during transfer and disposal operations.

4.1.1 General design approach

Radiological risks (external exposure risks, internal exposure risks and potentially criticality risk) likely to be encountered during the disposal process could be associated with radiological protection failures, or interventions carried out close to a source of radioactivity. Equipment malfunction may lead to its immobilisation when being used to carry or handle a disposal package. This situation would result in the external exposure of maintenance personnel if the latter had to operate near the source of radiation in order to repair the failing equipment.

The design has to minimize the likelihood for such events, anticipate preventive measures, and provide for protective measures should a failure occur. The main preventive design option is to provide redundancy for the main operating components such as motorisation, lifting device cinematic chains, etc. An objective of a very low failure probability is set. For example, some specific design solutions of a cinematic chain have been developed in HLW nuclear facilities and enable to reach a reliability of 10^{-8}/h. A second layer of protective measures consists of providing means to repair the failed equipment in an irradiation free environment. The irradiation source is the waste package. One solution is to retrieve the waste package out of the disposal cell and undertake normal repair. Another solution (when too many packages are in the cell) is to design an emergency system so as to enable the waste package to be set down and have the emplacement equipment return unloaded to its maintenance area.

4.1.2 Transfer cask design and radioprotection performance

The radiological protection transfer casks used for transferring the disposal packages contain a single disposal package (due to total weight and size constraints). A transfer cask consists of a handling frame with a shielded container on top. The container itself is equipped with a shielded door for loading and unloading the packages from the side. As mentioned in previous sections, the transfer casks for ILW-LL disposal waste packages have a radiological protection function of limiting the exposure of personnel to below the limits of the annual dose rate fixed by Andra (5mSv/year i.e. a quarter of the 20mSv/y regulatory limit). The cask shielding envelope is dimensioned in order to limit the dose rate to 3µSv/h at 1 metre from the cask.

4.1.3 ILW-LL disposal cell: shielded doors, waste transfer and handling

The design features for normal operations are shown in **Figure 8**. The transfer cask is docked to the shielded door of the disposal cell before opening. All the subsequent transfer operations are remotely controlled until the disposal package is set in place inside the disposal cell. The general design approach of in-cell mechanical equipment reduces the failure risk and provides with reliable solution in order to repair equipments. As the disposal cell will be progressively filled up, it has been necessary to provide a second shielding barrier, in order to ensure normal maintenance of the equipment. In normal operations this design limits the level of radiation to the personnel.

All failures that would occur in the radiation protection chamber will be addressed by providing specific means for evacuation of the waste package out of that chamber, either by getting it back into the shielded cask, or by transferring it into the disposal cell just behind the second shielded barrier. One specific means consists in providing an interface on the equipment for manual operation from outside of the chamber in case of full motor failure.

Failure of the lifting machine in the disposal cell is considered as highly unlikely. However a further layer of design is developed in order to tackle a loss of any handling axis on the machine The horizontal axis failure recovery design consists for instance in placing a towing machine ahead of the lifting machine; the towing machine cable is manoeuvred from the radiation protection chamber by a winder. The vertical axis failure would be mitigated by specific tools in the radiation lock after having brought back the lifting machine at the vicinity of the shielded door.

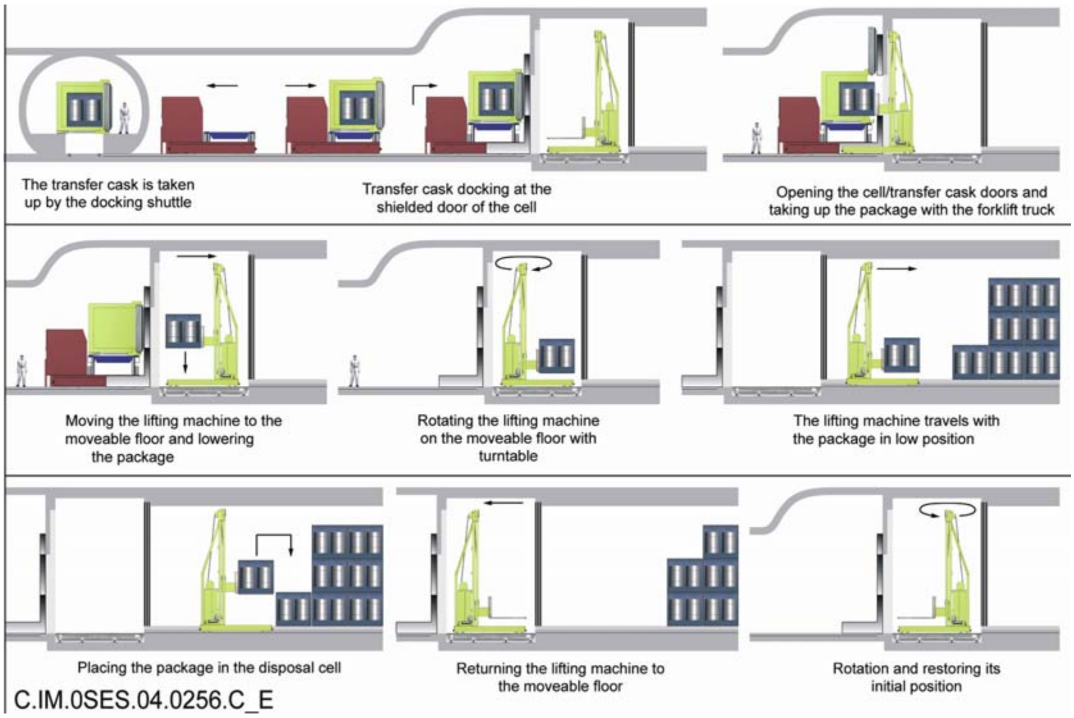


Figure 8 : Synopsis of unloading and cell disposal operation for ILW-LL waste

4.2 Waste disposal package drop risk in the ILW-LL disposal drift

ILW-LL waste disposal packages have to be emplaced by a remotely controlled vehicle by an operator located outside the cell. Drop prevention design features and consequences of an accident while stacking are discussed below. This analysis is intended to confirm the validity of the design for this risk as it relates to both the disposal package and the handling machine.

4.2.1 Prevention design features for the handling process

Various envisaged design options have been analysed throughout the engineering studies. The criteria for their selection include technical feasibility, operational safety, long term safety and costs. Specific design features limit the occurrence of the drop risk (prevention) and its consequences, so that operational safety requirements are mainly focused on the handling (or lifting) machine.

The waste disposal package is carried by the fork lift in the lowered position over the whole length of the disposal cell in order to limit the consequences of a drop risk. A basic requirement is to ensure good stability with the load in all possible positions on the lifting system. This has resulted in discarding a traditional fork lift system with counterweight, and to design instead a lifting machine with a specific frame, providing for a better location of the centre of gravity.

The package lifting and emplacement is the most sensitive part of the operation where the drop risk is concerned. During this operation, an error in the positioning of the expected position of the package to be emplaced, or a malfunction of the lifting system, could result in a fall from a height of 4 to 6 m (in the case of packages placed on the highest levels of the stacks).

There are multiple preventive measures. They include provisions such as brakes and safety sensors, redundancy of various components of the lifting system, double electric power supply, a device for lowering the load in the event an anomaly is detected, etc. Furthermore, stacking operations include a monitoring of the waste package emplacement cycle (validated step by step by the operator using cameras) and checking that the emplacement position matches the pre-designated location.

4.2.2 Analysis of the gravity and consequences of a drop event

The preliminary assessment of the mechanical consequences of a package drop was made for the standard container represented by a 6 metric ton type of ILW-LL waste disposal package. This assessment is based on the worst case drop scenario.

<u>Definition of the worst case</u>: The height of 6 m corresponds to the maximum handling height of the disposal packages during emplacement in the disposal cells. The top of the package (lid side) is more fragile than the bottom. So the retained worst drop case is a flipping and turning over of the waste disposal package followed by a vertical fall of the package onto a rigid floor. In order to maximise the damages, the centre of gravity of the package is vertically aligned to the point of impact. Three configurations have been discussed: “drop on a flat surface”, “drop on an edge” and “drop on a corner”.

The safety analysis for radioactive release is mainly focused on the integrity of the primary package. So the worst situation is the one which maximises the damage to the primary package. For the primary package located near to the impact point, the corner drop situation appears to be the severest.

<u>Drop consequences</u>: The disposal waste packages provide protection for the contained primary packages. In order to examine what the impacts would be and to quantify the deformations of the waste disposal package and the primary packages, a simulation tool has been used. It has been qualified by comparison with full-scale B2 and B5 waste disposal package drop tests which were run in 2005 (see **Figure 9**).

Figure 9: Corner drop test on disposal package and bitumen drums – Comparison with simulation

4.2.3 Recommendations for mitigation system designs

The results of the studies and tests on the mechanical consequences of ILW-LL waste packages falling in the disposal cell gives grounds for believing that there would be no loss of containment of radioactive material should such an event occur. However safety analysis goes further and provides design requirements for the disposal cell and its ventilation system. Scenarios involving the release of radioactive materials have been envisaged; assuming that the disposal package loses its initial leak tightness (on lid side) and that a primary waste package could be damaged to some extent. The contaminated air of the repository cell would circulate in the air return circuit before being rejected into the atmosphere at the exhaust shaft. This analysis indicates the need for a specific ventilation system for the disposal cell with HEPA filters and a leak-proof design (pressure in the disposal cell and ventilation system has to be lower than the atmosphere pressure in the surroundings).

4.3 Hydrogen explosion risk

Some types of ILW-LL waste packages emit gases which can concentrate and cause an explosion if their concentration exceeds their lowest explosive limit. The gas release is mainly caused by radiolysis which is associated with the effect of ionizing radiation emitted by radioactive materials on hydrogenated products present in the waste packages (organic materials, water in the conditioning matrix). These radiolysis off-gases are mainly hydrogen (more than 90% of the gaseous releases) and, to a lesser extent, methane. Radiolysis design flow rate of hydrogen amounts to 10 l/primary package/year. In a "B2" disposal cell, approximately 10,000 primary packages (drums) are stored, so the associated hydrogen production amounts to 100 m^3/year (274 l/day).

The operational safety analysis reviewed the designs for the disposal waste package, shielded transfer cask, and disposal cell systems in order to make recommendations for preventing any hydrogen explosion risk for wastes that release radiolysis off-gases. Controlling the risk of explosion involves the constant ventilation of installations until the closure of the disposal cell. Even if the ventilation breaks down, the low emission rates leave enough time to re-establish it. If waste removal is necessary after closure, ventilation will need to be re-established in order to release the accumulated gases in the cell according to suitable security measures (e.g. drilling under air lock protection with injection of neutral gas). Specific measures will also be needed during the sealing phases when the disposal cell is no more ventilated. The design process related to explosion risk reduction is described for each of the main components: disposal package, transfer cask, disposal cell (in operation and sealing phases).

4.3.1 Prevention design features for the disposal package design

Disposal package design has to ensure gas evacuation in order to limit the internal hydrogen concentration and to avoid pressure rise inside the package. Two design options have been considered in order to limit the internal hydrogen concentration to less than 2% (Andra's constraint in order to stay below the 4% explosive limit). In the first option, the package concrete lid is designed to allow gas release to the exterior (use of the porosity of the concrete). The concrete lid thickness must therefore not exceed 15 cm, as the gaseous diffusion coefficient in concrete under wet conditions diminishes considerably for greater thicknesses. The alternative option is to provide hydrogen vents within the concrete body of the disposal package.

4.3.2 Transfer cask

Hydrogen is also released inside the transfer cask during the transfer of the packages to the disposal cell. The existence of the transfer cask door construction clearances and, where applicable, the presence of a vent, will allow the hydrogen produced by the packages to be diluted in the atmosphere of the drifts and there will be no risk of an explosion, given the low hydrogen emission rate compared to the ventilation flow rates.

4.3.3 Disposal cell design for operational phase

The disposal cell ventilation is in operation until cell sealing. It is set at airflow of 3 m^3/s which corresponds, for a 250 m-long cell full of packages, to an air renewal rate per hour of 5. Hydrogen emitted by the waste disposal packages dilutes in the free space around the disposal packages and is evacuated by the ventilation. A simulation was carried out with a ventilation failure in a 250 m long disposal cell filled with type B5.1 packages. Average values of gas emitted from the packages have been used as they correspond to several hundred or thousand packages. Hydrogen was then concentrated in the top 15 cm of free space in the disposal cell, above the waste disposal packages. Under these conditions, the time taken to reach the 4% explosive limit is around 30 days. There is therefore no risk of explosion, even assuming a temporary ventilation failure.

4.3.4 Disposal cell sealing phase

At the end of the filling of the disposal cell, and when the Authorisation is given, the disposal cell has to be sealed. The ventilation has to be maintained as long as possible during all the stages of the sealing process. The duration of sealing operations without ventilation shall be well below the 30 days limit. A concrete retaining plug fills the open end of the disposal cell and thus isolates the waste disposal packages from the access drift. Under these conditions, the release of hydrogen into the access drift would be very slight and could not be the source of an explosion, all the more so since this drift will be ventilated throughout the fitting of the swelling clay core seal.

4.4 Fire hazard in underground installations

Fire remains one of the major preoccupations in an underground environment, since it develops in a semi-confined space, and the associated smoke and toxic gases may spread through the drifts into the installations, impede personnel evacuation and endanger a large number of persons.

4.4.1 Prevention design features

The initial design recommendation is to minimize the amount of calorific load available for a fire, in order to lower the consequences of a potential fire.

The equipment used to transfer the waste packages up to their final emplacement have been chosen accordingly. The vehicle used to transfer the transfer casks from the shaft is a self-propelled electric transport vehicle on tyres. An electrically powered shuttle on rails is used for the final move of the transfer cask through the access drift to the docking emplacement on the shielded door of the disposal cell. The fork lift (emplacement vehicle) used to transfer the disposal packages from their transfer cask to their final emplacement in a disposal cell is also a self-propelled electric vehicle on rails.

4.4.2 Design recommendations driven by the analysis

The risk assessment study is based on the assumption of a fire breaking out either (i) in a transfer cask on the transfer vehicle or shuttle (see Error! Reference source not found.), or (ii) in a waste disposal package handling vehicle inside the disposal cell. In both cases, in addition to the usual consequences resulting from a fire (temperature increase, smoke, etc.), the fire could have radiological consequences if it affects the function of maintaining the containment of the primary package. Among all the ILW-LL wastes, bituminous waste (B2) is chosen for the simulation study, because the bituminised matrix of the wastes for this type of package is the most sensitive to a temperature rise.

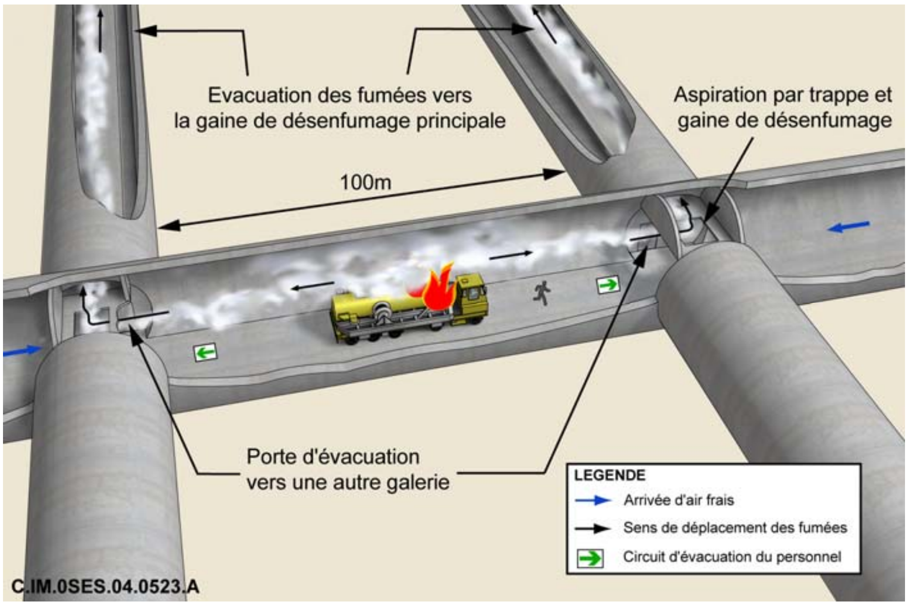
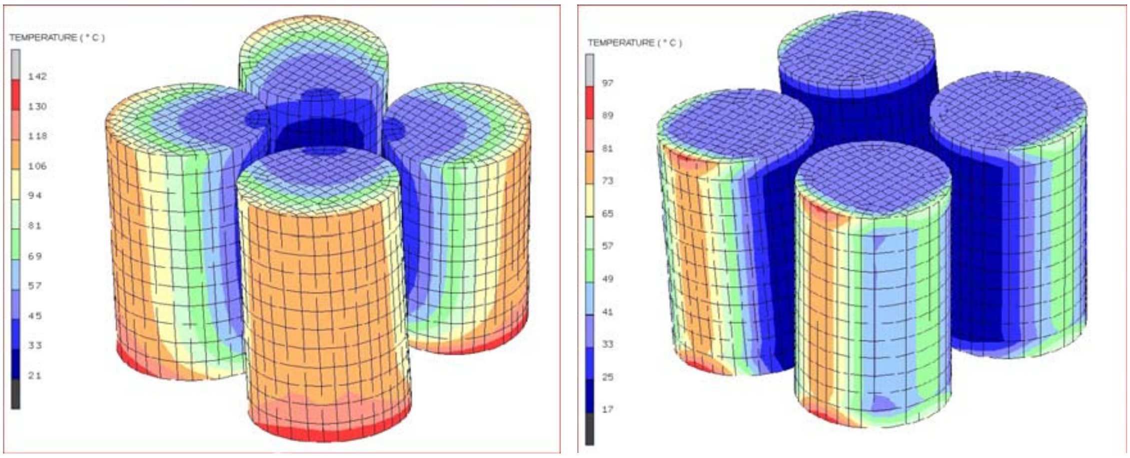


Figure 10: illustration of fire situation and escape of operators

<u>(i) For the transfer vehicle (or shuttle)</u>
The reference fire studied is located in the underground installations. It was defined from the specific characteristics of the vehicle and the recommendations of the Road Tunnel Study Centre (CETu); it corresponds to a fire with a heat rating of 15 MW for duration of one hour. The scenario takes into account the existence of a thermal layer included in the cask shield. The fire breaks out and spreads in a connecting drift with a normal operating ventilation system. .

<u>(ii) For the forklift during waste emplacement in the disposal cell</u>
The fire considered would occur during the transfer of the disposal package between the cell's entrance and the already disposed stacks of packages. The fire would be electrically caused and would imply the vehicle's batteries and motors as the origin. The vehicle's motor section with the battery rack is isolated from waste package by a 2 cm thick thermal shield. The fire's characteristics are based on the vehicle's characteristics; it corresponds to a heat rating of 3 MW for half- hour duration. This fire breaks out in a disposal cell with a 3 m^3/s ventilation rate. The simulations have been made on the

basis of assumptions regarding the heat ratings involved and the nature of the exchanges in the course of the fire (see **Figure 11**).



Results for transfer vehicle fire (15MW) Results for forklift fire (3 MW)

Figure 11: Temperatures reached at the level of primary packages

5 Synthesis and the Way Forwards

Reviews of the Dossier 2005 Argile were conducted by the National Regulatory Authority (ASN with the help of its technical support IRSN), by the National Evaluation Council (CNE) and by an international review team under the auspices of the Nuclear Energy Agency (NEA) of the OECD. A national public debate was then organised and on 28 June 2006, the new 2006 French Programme Act was published. According to that new French Act the reversibility of the waste disposal in a deep geological formation has to be envisaged and the corresponding studies and investigations shall be conducted by Andra with a view to selecting a suitable site and to designing a repository in such a way that, on the basis of the conclusions of those studies, the application for the license of building such a repository will be examined by the ASN in 2015 and, if the authorisation is granted, the repository will be commissioned in 2025.

The safety assessment is not an autonomous domain of the repository feasibility study. It forms an integral part together with the engineering (design) and research studies on site characterisation and phenomenological evolution of the repository. Research and design work is by nature an interactive activity between engineers, scientists and safety assessors. The repository architecture proposed within the framework of the Dossier 2005 is the result of these exchanges and takes into account what was learned from the preliminary safety assessment (risk analysis and quantification of selected scenarios) which rely on safety functions.

Together with design studies, operational-safety studies have helped to provide technical orientations and to propose proven risk-reduction measures. At the current stage, no study has detected elements that jeopardise either the technical feasibility of the construction, operation and closure of the repository, or its stepwise reversible management. Some results were confirmed by tests on demonstrators (e.g. drop test for ILW-LL package, etc.).

Regarding the future, according to the French Act of 2006, Andra’s program is moving towards a more detailed repository design and a related more detailed safety case combining both operational and long-term safety needs and assessments through a stepwise design process.

In view of the licensing application, some challenging issues need to be resolved before the 2014 license application such as the identification of the main design constraints induced by the intersection of operational and long-term safety constraints (e.g. gas explosion during operational phase and gas transfer during post closure phase).

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