ONDRAF/NIRAS

Waste Plan

for the long-term management of conditioned high-level and/or long-lived radioactive waste and overview of related issues

NIROND 2011-02 E September 2011

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This document is the result of extensive team work conducted within ONDRAF/NIRAS and with Brigitte Cornélis — freelance scientific writer — who wrote it. It is also available in French and Dutch.

The Executive Summary has been published on its own under reference NIROND 2011-04 E (rev. 1). This publication replaces the Executive Summary first published under reference NIROND 2011-04 E. The revised version differs from the first publication only in that the translation from the original language has been improved. The content of the Executive Summary remains unchanged.

The Executive Summary is also available in French, Dutch and German. It was published in these three languages in the Belgian Official Journal of 30 September 2011.

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Preamble

The ONDRAF/NIRAS Waste Plan aims to satisfy the requirements of

- the Royal Decree of 30 March 1981 as amended determining its missions and establishing its functioning rules, which requires it to have a general programme for the long-term management of radioactive waste,
- and the Law of 13 February 2006 relating to the assessment of the environmental impact of certain plans and programmes and to public participation in drawing up plans and programmes relating to the environment,

while also satisfying the request made by its supervisory authority in 2004 to plan and begin a societal dialogue on the long-term management of conditioned high-level and/or long-lived waste (B&C waste) and evaluate all possible strategies for this management with a view to enabling a decision on the management solution to be implemented to protect man and the environment as long as this waste presents a risk.

The ONDRAF/NIRAS Waste Plan was adopted by the ONDRAF/NIRAS Board of Directors, the only authority entitled to do so, on 23 September 2011. It was finalised by ONDRAF/NIRAS following the opinions and comments issued during the summer of 2010 as part of the legal consultation procedure with various official institutions and the public to whom, in accordance with the provisions of the Law of 2006, ONDRAF/NIRAS submitted the draft Waste Plan and the accompanying *strategic environmental assessment* or SEA. It replaces and cancels the draft Waste Plan. The Waste Plan has also been updated in order to reflect changes in the national and international situation and foreign programmes that have occurred since June 2010: it reflects the situation as at 31 July 2011. However, it does not take into account the European Directive of 19 July 2011 for the responsible and safe management of spent fuel and radioactive waste, except by adding an annex which contains some of the key points of this Directive directly related to the Waste Plan and a first analysis of the Waste Plan's contribution to compliance with the Directive's requirements. Since the Law of 2006 does not provide for the SEA to be changed following the legal consultation, the SEA remains unchanged.

In its opinion on the draft Waste Plan and the SEA, the SEA Advisory Committee established by the Law of 2006 did not identify any deficiencies regarding the way in which the legal procedure was implemented. It *"appreciates the investment that ONDRAF/NIRAS has made to ensure the correct implementation of the environmental assessment procedure, particularly by producing a version of the index that takes its comments into account."* It also noted that *"The documentation is complete […]."* [translation ONDRAF/NIRAS]

Through its Waste Plan, ONDRAF/NIRAS intends to satisfy its legal obligations while providing the Government with all the elements it needs to make a fully informed *decision in principle*, in other words a general policy decision, about the long-term management of B&C waste, including irradiated fuel declared as waste. The Waste Plan is therefore a strategic document. It is not intended to detail all the arguments, notably the scientific, technical and financial ones, underpinning the management solution recommended by ONDRAF/NIRAS. These arguments are broadly documented in the national and international scientific literature to which the Waste Plan and the SEA refer.

The Waste Plan and SEA are in fact based on scientific and technical knowledge that goes far beyond the knowledge acquired as part of the Belgian programme, and even programmes for the long-term management of radioactive waste in general.

The Waste Plan as adopted will only be implemented by means of Government approval through a decision in principle, needed as soon as possible, establishing a clear policy in terms of the long-term management of B&C waste. The gradual development of this policy should be guided by a normative system that must also be developed.

Two documents accompany the Waste Plan and the SEA:

- the declaration which, in accordance with the provisions of the Law of 2006, summarises notably the way in which the SEA and the consultations conducted during the legal procedure have been taken into consideration in the Waste Plan;
- the report from the citizens conference organised in late 2009 – early 2010 by the King Baudouin Foundation at the request of ONDRAF/NIRAS and dedicated to the issue of how to decide on the long-term management of B&C waste.

Executive Summary

In Belgium, the legislature entrusted the management of radioactive waste to a public institution with legal status: the Belgian Agency for Radioactive Waste and Enriched Fissile Materials, known by the French/Dutch acronym ONDRAF/NIRAS. This management must ensure the protection of man and the environment against the risks associated with this waste, and therefore includes an important long-term component. Conditioned short-lived low-level and medium-level waste, called category A waste, presents in fact a risk for man and the environment on a timescale of hundreds of years. A common feature shared by the other conditioned wastes managed by ONDRAF/NIRAS, namely those from categories B and C, also called B&C waste, is that they also present a risk, but on a timescale of tens to hundreds of millennia owing to the quantities of long-lived radionuclides that they contain. B&C waste is high-level and/or long-lived waste.

The long-term management of radioactive waste is under the exclusive competence of ONDRAF/NIRAS. In accordance with the legal framework, this long-term management must ensure that the waste is disposed of in a long-term management facility without *intention* to retrieve, this facility being then its final destination. However, the fact that the waste is not intended to be retrieved does not necessarily preclude retrieval or controls.

Contrary to the situation for category A waste, no institutional policy has yet been formally approved in Belgium for the long-term management of existing and planned B&C waste, including non-reprocessed irradiated nuclear fuel declared (or likely to be declared) as waste, as well as excess quantities of enriched fissile materials and plutonium-bearing materials (excluding fuel) declared (or likely to be declared) as waste.

> *In the rest of the text, the phrase "B&C waste" must be understood as also referring to non-reprocessed irradiated nuclear fuel declared (or likely to be declared) as waste, as well as excess quantities of enriched fissile materials and plutonium-bearing materials (excluding fuel) declared (or likely to be declared) as waste.*

The relevance and the quality of research, development and demonstration (RD&D) activities in the field of long-term management of B&C waste, initiated in 1974 by the Belgian Nuclear Research Centre (*Studiecentrum voor Kernenergie / Centre d'Etudes de l'Energie Nucléaire* or SCK•CEN) and with the responsibility transferred to ONDRAF/NIRAS a decade later, have been confirmed several times since 1976 by different commissions and working groups asked by institutional bodies to give an opinion on ongoing studies in the field of long-term management of B&C waste or on energy policy issues. However, the direction taken — *geological disposal in poorly indurated clay* (in Belgium, Boom Clay or Ypresian Clays) — has not been *formally* confirmed or refuted at the federal level.

It is the responsibility of the countries that have signed the 1997 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, including Belgium, to have long-term management policies for these materials. Following the ratification of this convention, Belgium transposed it into its legislation in 2002. Independent of the countries' future energy policies, this national responsibility is also one of the basic principles laid down in the European Directive of 19 July 2011 for the responsible and safe management of spent fuel and radioactive waste ("Waste" Directive). (The Waste Plan does not take this very recent Directive into account, except by adding an annex mentioning the key points of the Directive directly related to the Waste Plan and providing a first analysis of the Waste Plan's contribution to compliance with the Directive's requirements.)

An institutional policy for the long-term management of B&C waste is essential for many reasons, in particular to enable ONDRAF/NIRAS to focus the RD&D activities still required according to the final destination of this waste, to help it determine and optimise all the upstream aspects of management, to enable it to apply the "polluter pays" principle on a firmer basis than today, to address the current uncertainty relating to storage duration in the municipalities where this waste is currently temporarily stored, and to avoid passing the management responsibility, including all associated burdens (technical, financial, decision-making, radiological, etc.), on to future generations, in accordance with the intergenerational equity principle put forward in the Joint Convention and the "Waste" Directive.

1 Waste Plan: motivation and scope

Whereas in particular

- ONDRAF/NIRAS is legally bound to have a general programme for the long-term management of radioactive waste;
- a long-term management policy for B&C waste is *necessary*;
- the ONDRAF/NIRAS RD&D programme for long-term management of B&C waste, which is in line with international recommendations, has attained an advanced level of technical maturity, which renders *possible* a general policy decision in this field;
- ONDRAF/NIRAS in 2004 was entrusted by its supervisory authority to prepare and start societal dialogue at all levels on the long-term management of B&C waste and to assess all possible strategies for this management in order to enable a decision on the management solution to be implemented;
- the Law of 13 February 2006, on the one hand, requires that the general programme for the long-term management of radioactive waste be subject to an environmental assessment and that this assessment (strategic environmental assessment or SEA) include an evaluation of the likely impacts of the "reasonable alternatives", and, on the other hand, provides for public participation in the development of this programme;

ONDRAF/NIRAS has taken the initiative to compile in a single document, the *Waste Plan*, all elements necessary to enable the Government to make, with full knowledge of the facts, a *decision in principle*, i.e. a *general policy* decision or a *general guidance* decision, relating to the long-term management of B&C waste. Such a decision is not a decision for the immediate implementation of a specific solution at a given site.

The Waste Plan focuses on the long-term management of B&C waste, considering only existing and planned (mainly within the scope of the current nuclear power programme) waste. According to the ONDRAF/NIRAS 2009 estimate, the volumes of B&C waste to be managed by 2070, i.e. by the end of the activities relating to the dismantling of all existing nuclear facilities or of all nuclear facilities of which the construction was planned as of 31 December 2008, are the following:

- 11 100 or 10 430 m^3 of category B waste, depending on whether the current suspension of commercial irradiated fuel reprocessing is lifted or maintained. This waste originates mainly from research activities, nuclear fuel production, reprocessing of irradiated fuel and dismantling of nuclear power plants and research and fuel production facilities.
- 600 or 4 500 m^3 of category C waste, depending on whether the current suspension of commercial irradiated fuel reprocessing is lifted or maintained. This waste is vitrified waste resulting from reprocessing commercial irradiated fuel and non-reprocessed irradiated fuel declared as waste.

A large part of this waste already exists or will inevitably be produced.

The long-term management of category A waste is mentioned in the Waste Plan for the record, since the management solution to be carried out for this waste — a surface disposal facility in the municipality of Dessel within the scope of an integrated project providing added value for the region — was decided by the Council of Ministers on 23 June 2006.

Finally, the Waste Plan identifies a series of issues, the answers to which are not a matter solely for ONDRAF/NIRAS, but are likely to impact the long-term management of B&C waste (such as the status — resource or waste — of commercial irradiated fuel, as well as of enriched fissile materials and plutonium-bearing materials excluding fuel), or even on its management activities in general. Thus, the Waste Plan touches on the development of one or more management systems complementary to the existing system in order to ensure the long-term management of substances that currently do not have radioactive waste status but could acquire it later on, or of radioactive waste for which no application has yet been submitted in order for ONDRAF/NIRAS to take charge of it.

The ONDRAF/NIRAS general programme for the long-term management of radioactive waste will ultimately include, in addition to the Waste Plan, one or more other dedicated plans covering the management of all substances that have or will have radioactive waste status. These plans will be established as the corresponding issues become sufficiently mature.

2 Development of the Waste Plan and procedural aspects

With a view to developing its Waste Plan, ONDRAF/NIRAS decided to conduct an assessment of the possible options for the long-term management of B&C waste and a societal consultation broader than those required by the Law of 13 February 2006.

- In the Waste Plan and the SEA on which it is based, all possible options for the management of B&C waste were considered in the broadest possible way.
- The development of the document which preceded the Waste Plan, called "draft Waste Plan", and of the SEA was improved using the results of a societal consultation organised on the initiative of ONDRAF/NIRAS long before the consultation procedure imposed by the Law of 13 February 2006.
- The assessment of these options within the scope of the SEA was not limited to environmental impacts, but also included, as far as practicable, the environmental and safety, technical and scientific, financial and economic, and societal and ethical aspects.

The Waste Plan and the SEA are the outcome of a multi-step development process regulated by the legal procedure laid down in the Law of 13 February 2006. In accordance with the provisions of this law, ONDRAF/NIRAS submitted the draft Waste Plan and the SEA for an opinion to the Advisory Committee set up by this law (hereafter called the "SEA Advisory Committee"), to the Federal Council for Sustainable Development, to the Governments of the Regions, and to the public. As allowed by law, ONDRAF/NIRAS also submitted these documents for an opinion to the nuclear safety authority (the Federal Agency for Nuclear Control or FANC). In its opinion on the draft Waste Plan and the SEA, the SEA Advisory Committee did not identify any deficiencies regarding the way in which the legal procedure was implemented.

In finalising the Waste Plan, ONDRAF/NIRAS took into account the opinions of the official institutions and the comments of the public provided during the legal consultation procedure. In accordance with the provisions of the Law of 2006, it also issued a declaration, which among other things summarises the way in which the SEA, as well as the opinions and comments received, were taken into account in finalising the Waste Plan.

The Waste Plan was adopted by the ONDRAF/NIRAS Board of Directors, the only authority entitled to do so, on 23 September 2011. *Commencement of its implementation must be approved by a decision in principle at the federal level.*

3 Assessing and comparing options

In the Waste Plan and the SEA on which it is based, all possible options for the long-term management of B&C waste were considered *in the broadest possible way* (Figure 1). Some options were immediately rejected as they are in violation of international treaties or conventions to which Belgium is a signatory (for instance sea dumping and disposal in ice sheets), and/or the Belgian legal and regulatory framework (for instance disposal by injecting waste in liquid form deep underground), and/or do not provide adequate safety guarantees (for instance surface disposal). The remaining options, i.e. eternal storage, geological disposal, disposal in deep boreholes, extended interim storage with a view to or awaiting "something else", and the option consisting in maintaining the current situation (status quo) were then subjected to a cross-disciplinary assessment within the scope of the SEA and the Waste Plan. The SEA Advisory Committee confirmed in its opinion that the choice of possible options is coherent with the approach adopted in the other countries facing similar problems.

As the Waste Plan aims to enable a strategic decision — not a decision relating to a specific project —, management options were considered in generic terms in the Waste Plan and the SEA, i.e. without linking them to a particular site. This means neither document addresses siting issues nor, *a fortiori*, facility design. Consequently, the option assessment exercise was mainly qualitative, relying on expert judgement based on the knowledge (entirely open) available at national and international level and, insofar as possible, on similar studies abroad and the consequent decisions, as well as on feedback from existing similar facilities in Belgium and abroad. However, quantitative analyses were carried out whenever possible and appropriate. Due also to the strategic nature of the Waste Plan, transboundary environmental impacts were not assessed. The SEA Advisory Committee confirmed in its opinion that such an assessment was not yet possible.

Once the assessment of the options was completed, the various options envisaged for the long-term management of B&C waste were narrowed down to two strategic options: disposal of the waste in an appropriate geological formation, or extended interim storage with a view to or awaiting "something else". The eternal storage option is considered inadequate to ensure long-term safety, disposal in deep boreholes is not reasonably possible for the long-term management of the total volume of B&C waste, and the status quo option is not a long-term management solution and therefore does not enable ONDRAF/NIRAS to fulfil its management mission.

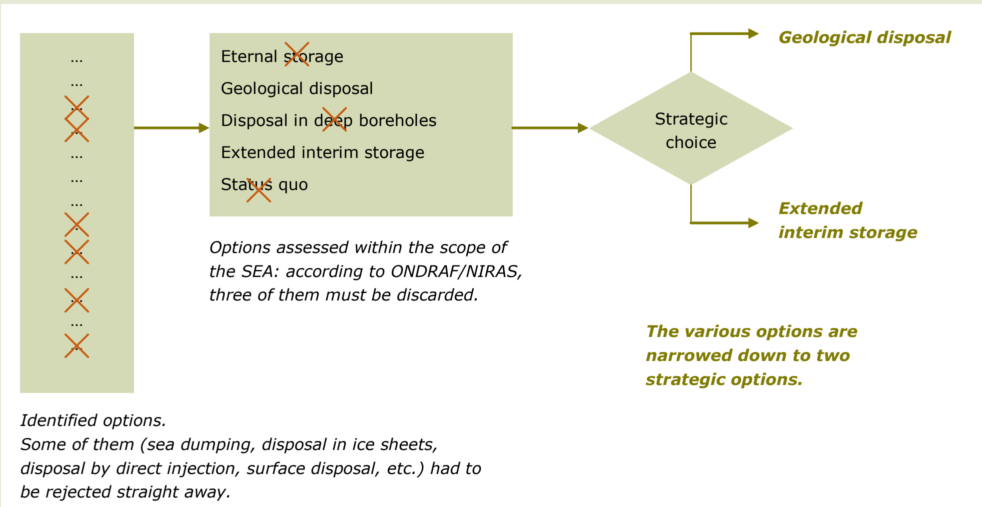


Figure 1 – Gradual process of discarding unreasonable options for the long-term management of B&C waste.

The major difference between geological disposal and extended interim storage (100 to 300 years) is the fact that a storage facility is not the final destination of the waste. Therefore, extended interim storage is not a management solution designed to become definitive, contrary to a geological disposal facility, which can also become a system that can ensure safety in a passive way after complete closure (i.e. without human intervention being necessary, which does not mean that controls are absent or impossible). On the other hand, the operational period (construction, operation, closure) of a geological disposal facility (approximately one hundred years) requires active management and is, in this respect, similar to the operational period of a storage facility.

The comparison between geological disposal and storage lasting 100 to 300 years highlights two aspects which, according to ONDRAF/NIRAS, decisively weigh in favour of geological disposal as a solution for the long-term management of B&C waste (see also Figure 2).

- The *robustness* of geological disposal with respect to future evolution (societal, natural, etc.), i.e. the fact that the safety of a repository system appropriately designed and implemented is not unacceptably affected by future evolution. On the other hand, the safety of storage requires active management and is, therefore, particularly dependent on societal evolution: safety might no longer be ensured if active management is disrupted.
- The fact that geological disposal passes *minimum burdens* on to future generations. By contrast, any storage solution *de facto* transfers the whole management responsibility, including considerable burdens, to future generations, which will have to decide on a solution that can become definitive, or on a new storage period at the end of the extended interim storage period.

According to ONDRAF/NIRAS, a geological disposal facility — progressively developed, implemented and closed, if need be after a period of *in situ* controls — is the only management solution capable of protecting man and the environment in the long term against the risks associated with B&C waste, and of minimising the transfer of burdens to future generations while leaving them some freedom of choice, in particular regarding control of the repository, closure planning, possible retrieval of waste and knowledge transfer to the next generations. This solution is in line with international recommendations and practices.

CURRENT SITUATION

Interim storage

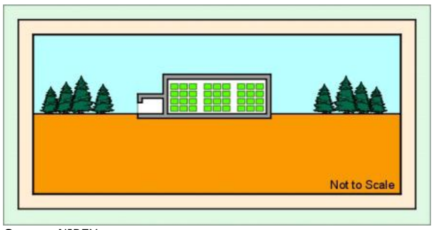
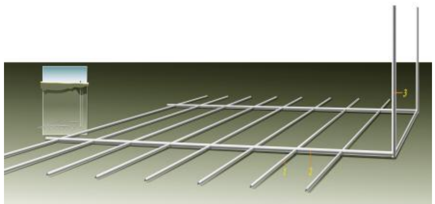
Planned duration: approx. 75 years
Safety subject to maintenance and controls

The stored waste is to be transferred to a long-term management facility.

Strategic choice of long-term management (part of the decision in principle)

OR

DESIRED SITUATION: Solution ensuring the protection of man and the environment for as long as the waste presents a risk (several tens to several hundreds of millennia)

	Extended interim storage	**Geological disposal**
	 Source: NIREX	
Safety	■ ensured, subject to continuous maintenance and controls	■ inherent to the system for geological periods (million years)
Main uncertainties	■ societal ⇒ cannot be managed (uncertainty whether future societies will continue to ensure the necessary controls with a view to long-term safety)	■ scientific and technical ⇒ taken into consideration in the development and assessment of a robust disposal system; no prohibitive defects have, however, been found during 30 years of RD&D in some twenty countries
Life expectancy of the system	■ limited by technique (in principle to 300 years)	■ ensured by choosing a stable formation
Vulnerability to natural events	■ protection ensured by technique	■ protection ensured by host formation
Transfer of burdens	■ burdens completely passed on to future generations	■ minimum burdens passed on to future generations
Retrieval of waste	■ possible at any time	■ possible, but becoming more difficult over time
Controls	■ essential for ensuring safety	■ not essential for safety, but intended to be maintained for a duration still to be determined
Knowledge transfer	■ essential for ensuring safety	■ not essential for safety, but planned
Integration of the scientific and technical developments	■ possible at any time	■ limited to operational period
Polluter pays principle	■ not applicable because the solution which will replace storage is not identified	■ applicable on a concrete basis
Vulnerability to malicious acts	■ basically subject to controls	■ limited vulnerability because of depth
Type of solution	■ not justifiable according to safety authority (FANC)	■ solution recommended internationally
	is thus not a long-term management solution	***is thus a long-term management solution***
	Requires a new decision in principle with a view to a long-term management solution	*Strictly speaking, no further human intervention is required once the facility is completely closed. The combination "engineered barriers + geological host formation" retains the radionuclides which are finally released from the waste, and in this way protects man and the environment.*

?

Figure 2 – Key aspects of the strategic choice between geological disposal and extended interim storage.

4 The solution recommended by ONDRAF/NIRAS for the long-term management of B&C waste

For the long-term management of existing and planned B&C waste, ONDRAF/NIRAS recommends a *global* geological disposal solution, including a technical solution (section 4.1) that fits into a decision-making process integrating the technical and societal aspects (section 4.2), the development and implementation of which are accompanied by a series of conditions arising from the societal consultation organised on the initiative of ONDRAF/NIRAS and from the legal consultation (section 4.3).

4.1 Technical solution for the long-term management of B&C waste

The technical solution recommended by ONDRAF/NIRAS for the long-term management of B&C waste is a solution that can become definitive, namely

- geological disposal (section 4.1.1)
- in poorly indurated clay (Boom Clay or Ypresian Clays) (section 4.1.2)
- in a single facility (i.e. one facility for all B&C waste and built at a single site) (section 4.1.3)
- on Belgian territory (section 4.1.4)
- as soon as possible, but with the pace of development and implementation of the solution needing to be proportionate to its scientific and technical maturity, as well as to the public support it receives (section 4.1.5).

4.1.1 Geological disposal

Geological disposal

- is in line with the legal mission of ONDRAF/NIRAS, as it provides a final destination for B&C waste;
- is applicable to all existing and planned B&C waste;
- is considered by radioactive waste management organisations and safety authorities at national and international level as feasible and capable of ensuring the protection of man and the environment for several hundreds of millennia in a robust way and in an intrinsically passive manner;
- is confirmed by the results of the multidisciplinary analysis of the possible management options carried out within the scope of the SEA as *the only solution for the long-term management of B&C waste and certainly as the safest from a radiological point of view, the most robust in terms of future societal and natural evolution, and the most appropriate to protect man and the environment in the long term*;
- minimises the burdens transferred to future generations, in particular radiological risks, environmental impact and responsibility for ensuring safety, making decisions and ensuring financing;
- can be financed on the basis of the “polluter pays” principle;
- has been chosen by all countries that have an institutional policy for the long-term management of their B and/or C waste. The United States has operated

since 1999 a geological disposal facility for its category B military waste, and Finland, France and Sweden are, in principle, only 10 to 15 years away from starting the industrial operation of a geological disposal facility.

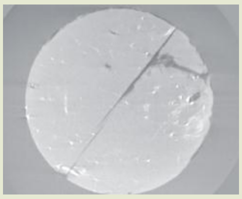
4.1.2 In poorly indurated clay (Boom Clay or Ypresian Clays)

Poorly indurated clays, in particular Boom Clay and Ypresian Clays, are the geological formations in Belgium that seem to present the best intrinsic properties to ensure the functions expected of a natural barrier, i.e. long-term isolation, confinement and retention of radionuclides and chemical contaminants present in a geological disposal facility. A disposal system (host formation + repository + waste) appropriately designed and implemented in these clays can ensure safety in the long term.

Poorly indurated clays as a long-term natural barrier to the migration of radionuclides and chemical contaminants

Thanks to their properties, poorly indurated clays are high-quality natural barriers to the migration of radionuclides and chemical contaminants towards the surface environment.

- They have a *very low permeability*. There is therefore practically no water movement in these clays and thus no radionuclide and chemical contaminant transport via this medium. As a result, transport is essentially diffusive, which means species migrate under the influence of their concentration gradient, not under the influence of the pore water movement.
- They have a *strong retention capacity* for many radionuclides and chemical contaminants (sorption capacity, favourable geochemical properties, etc.). Their migration through the clay is thus considerably delayed.
- They are *plastic*. Therefore, any fractures and fissures that could occur in the clays, in particular by excavation activities, tend to close by themselves (self-sealing capacity).



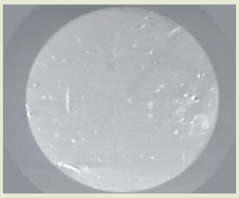


Illustration of the self-sealing capacity of Boom Clay. Left: clay sample in which a fracture has been induced. Right: the same sample 4 hours after hydraulic saturation: the fracture has been sealed.

The entire Boom Clay formation (about 100 metres thick) consists of different layers more or less rich in clay. However, radionuclide and chemical contaminant transport properties are very homogeneous almost throughout the entire thickness of the Boom Clay. In addition, Boom Clay and Ypresian Clays are present within simple geological structures, which facilitates their characterisation.

Finally, Boom Clay and Ypresian Clays are hydrogeologically, geochemically and mechanically stable over geological timescales, i.e. millions of years. Their components have remained unchanged since shortly after the deposition of the formations. Over this entire period, natural changes (earthquakes, sea level fluctuations, glacial periods, etc.) have not altered their favourable properties.

Disposal system description

The essential elements on which ONDRAF/NIRAS relies in designing a disposal system for B&C waste in poorly indurated clay that ensures operational and long-term safety can be summarised as follows.

- *Long-term safety:*
  - *Confinement* of category C waste must be ensured by engineered barriers (man-made barriers) for the period during which the properties of the host formation could become temporarily perturbed, in particular due to the rise in temperature (thermal phase). This period ranges from several hundreds of years for vitrified waste to several thousands of years for non-reprocessed irradiated fuel (provided that it was first cooled in surface storage for 60 years).
  - *Isolation* of the repository from external perturbations, such as climate change, earthquakes or human activities, must be ensured by the clay layer and its geological environment.
  - *Delay* in the migration of the radionuclides and chemical contaminants which will ultimately be released from the waste and the engineered barriers is essentially ensured by their retention in the clay.
  - Design of the repository, including techniques and material choices, is carried out in such a way that the clay, which is the most important barrier with a view to long-term safety, is *not unduly perturbed*.
- *Operational safety:*
  - The engineered barriers must ensure *radiological shielding* of the waste for the entire operational period (about 100 years), from the moment the conditioned waste is post-conditioned above ground to form supercontainers or monoliths (see below). They also aim to reduce the contamination risks in the repository.

The geological repository considered for B&C waste consists of a network of horizontal galleries built at mid-thickness of the clay layer, at a sufficient depth (Figure 3). Shafts lead to a main gallery which gives access to the disposal galleries, of smaller diameter. These galleries are divided into several sections dedicated to groups of wastes with similar characteristics (for instance their thermal output, their chemical composition or the nature of their conditioning matrix).

The system of engineered barriers considered for category C waste is based on the use of supercontainers aimed at ensuring full confinement of the radionuclides and chemical contaminants during the thermal phase. For handling reasons, category B waste is placed in concrete caissons and subsequently embedded in mortar to form monoliths. The supercontainers, as well as the monoliths, ensure radiological shielding to protect workers during operation and closure of the repository.

After emplacement of the waste, empty spaces in the disposal galleries are backfilled with materials chosen for their capacity to contribute to the system’s overall safety. All access galleries and shafts are backfilled and sealed at the end of the underground operations, if need be after a period of *in situ* controls. The system is then in a passive state.

After closure, the geological repository can be controlled from the surface, and future generations can prolong controls as long as they wish. Moreover, controls will be compulsory in case of the disposal of irradiated fuel, in order to prevent the risk of nuclear proliferation.

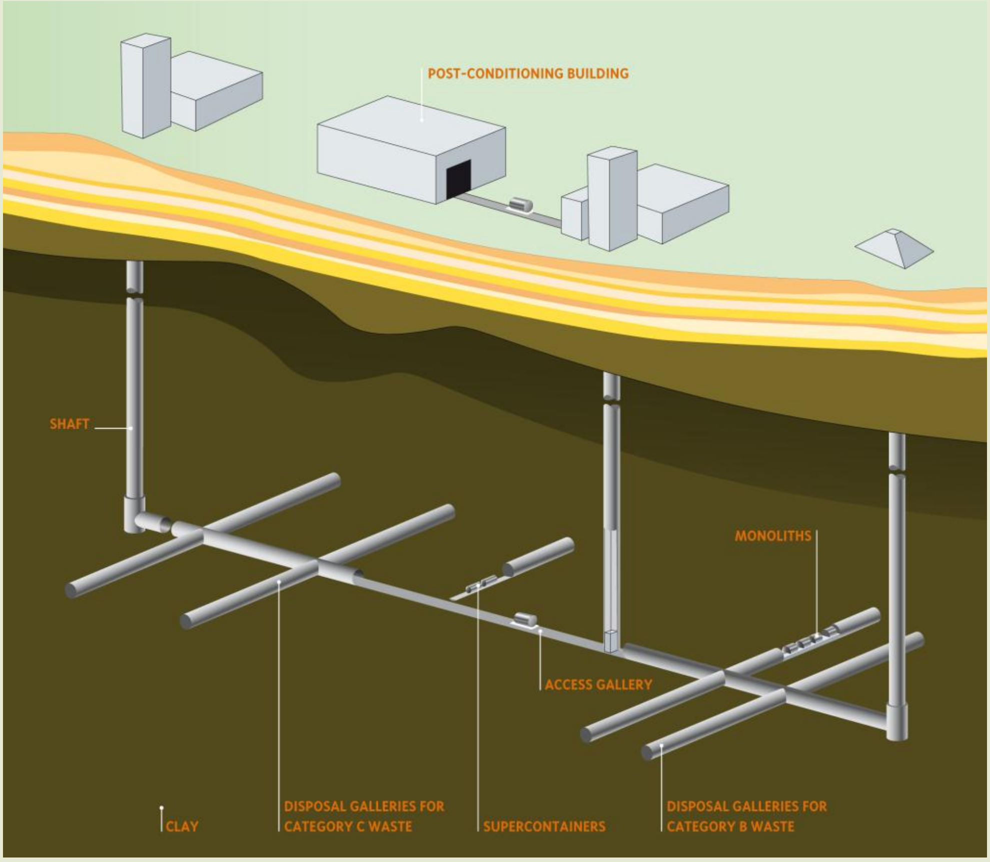


Figure 3 – Indicative diagram of the geological repository envisaged for B&C waste and of the surface facilities for the production of supercontainers and monoliths.

The solution of geological disposal in poorly indurated clay is flexible enough to adapt to the additional conditions to which its implementation could be subjected, such as those discussed in section 4.3, and to the potential variations identified in B&C waste volumes to be managed (section 5.1).

The latest estimate of the non-discounted total cost, including margins for technological and project risks, of geological disposal in Boom Clay at a depth of approximately 220 metres, in the event of full reprocessing of all commercial fuel, amounts to some EUR_{2008} 3 billion.

Long-term safety assessments

The impact of the repository in the long term was assessed on the basis of the considerable knowledge and expertise available at both national and international level.

The uncertainties about the evolution of the disposal system were analysed by taking them into account in a reasoned manner in a range of scenarios. This range includes the reference scenario, which describes the expected evolution of the disposal system, and its variants, a number of other evolution scenarios that are possible but less probable (for example substantial rise in sea level, earthquakes, glaciation, early failure of the engineered barriers), and human intrusion scenarios.

The main findings concerning the assessment of long-term safety under normal conditions were obtained for a repository assumed to be built in the middle of the 100-metre thick layer of Boom Clay in the region of Mol–Dessel. They are based on cautious (sometimes even pessimistic) assumptions that amount to introducing significant safety margins into the results obtained. They can be summarised as follows.

- Boom Clay is the main contributor to long-term safety.
- Engineered barriers make an effective contribution to long-term safety that largely exceeds requirements.
- Waste matrices play a minor part in long-term safety, except for the UO_2 matrix of nuclear fuel.
- The peak dose generated by the repository is at least 10 times lower than the regulatory limit:
  - the main contributors to the dose are the fission products that are not retained in the Boom Clay (^{129}I, ^{36}Cl, ^{14}C, etc.);
  - actinides (U, Pu, Am, Cm and Np) make only a very small contribution to the dose;
  - most radionuclides decay to insignificant levels within the engineered barriers or during their transport through the Boom Clay.
- The most mobile fission products leave the Boom Clay after some tens of millennia; actinides leave the Boom Clay after several hundreds of millennia. In both cases, the quantities are negligible.
- The presence of a geological repository in the Boom Clay has no negative impact on the aquifers on either side of the Boom Clay and does not preclude their exploitation as sources of drinking water.

The assessment of the other possible evolution scenarios and of the human intrusion scenarios does not result in conclusions that differ fundamentally from those obtained for the reference scenario.

In general, the long-term safety assessment results are coherent with the results obtained within the scope of the other national programmes in the field of geological disposal, which enhances confidence in these assessments.

The presence of aquifers on either side of the Boom Clay and the Ypresian Clays is of particular importance for ONDRAF/NIRAS, with respect to their radiological protection, the limitation of physicochemical perturbations (thermal impact, presence of chemical toxic elements, etc.), and the risk of human intrusion.

It is of course up to FANC and the authorities competent to deal with environmental protection to assess, within the scope of the licence application procedure for geological disposal, the degree of safety and protection provided by the disposal system developed, and to authorise its implementation.

Feasibility assessments

The construction of the underground research laboratory HADES, in particular the last extension phase, showed that it is possible to build shafts and galleries in the Boom Clay at a depth of more than 200 metres using industrial techniques while limiting the geomechanical perturbations of the clay. Moreover, the large-scale demonstration experiments confirmed the possibility of different types of operation, for instance backfilling of the disposal galleries, sealing of the shafts, and handling of the supercontainers and monoliths in shafts and galleries, according to known industrial methods. These achievements have been confirmed in other countries.

Peer reviews

Scientific and technical achievements in the field of disposal in poorly indurated clay, in particular 30 years of RD&D in the underground laboratory HADES, were assessed several times by Belgian and international experts. Their conclusions can be summarised as follows.

- The findings are based on sound science and have reached a sufficient degree of maturity for a favourable opinion to be given on the safety and feasibility of this solution. Ongoing research in other countries confirms the potential of clay formations for confining disposed waste and retaining radionuclides and chemical contaminants.
- The remaining uncertainties are systematically analysed and taken into account in the safety and feasibility assessments, which show that these uncertainties do not call into question the safety and/or feasibility of this solution. Reducing uncertainties is the main objective of ongoing and future RD&D programmes.

Moreover, the validity of activities with regard to disposal in poorly indurated clay has been confirmed several times by different Belgian commissions and working groups asked by institutional bodies to give an opinion on various issues including, to varying degrees, radioactive waste management.

Maturity of the technical solution and decision in principle

According to ONDRAF/NIRAS, none of the reasons that might prompt delay of a decision in principle supporting geological disposal in poorly indurated clay is justified. This solution is *technically sufficiently mature to be the object of a decision in principle,* since the uncertainties that still have to be addressed are not considered prohibitive. In addition, making such a decision now does not rule out the possibility of continuing RD&D in order to develop the geological disposal solution and prepare its implementation. To the contrary, continuing RD&D is essential and planned: it will progressively enable confirmation and refinement of knowledge so as to increase safety margins, reduce remaining uncertainties, and optimise the disposal system. Protection of the aquifers on either side of the Boom Clay and of the Ypresian Clays will be one of the focal points. A decision in principle supporting geological disposal in poorly indurated clay does not rule out either the feasibility of following up developments regarding management possibilities that were examined in the Waste Plan but were discarded. Moreover, in its opinion on the draft Waste Plan and the SEA, FANC confirms that surface disposal, *"be it pending the development of new techniques or for a period of several centuries"* [translation ONDRAF/NIRAS], cannot be justified.

Opting for geological disposal in poorly indurated clay as a solution for the long-term management of B&C waste limits the areas of the Belgian territory where a repository could be located to the north-east and the northernmost part of western Belgium. However, this choice does not imply that a site has to be chosen immediately.

4.1.3 In a single facility

According to ONDRAF/NIRAS, category B and category C wastes must be managed in the long term within the scope of a management solution — geological disposal — which, on the one hand, is common to both types of waste, since the risk they pose in the long term stretches over similar timescales, i.e. several tens or hundreds of millennia, and, on the other hand, is implemented at a single site, since their respective volumes are such that different facilities cannot reasonably be envisaged from an economic point of view. The geological disposal facility will, however, be designed and operated in such a way that waste with different properties will be placed sequentially and in different parts of the repository.

4.1.4 On Belgian territory

ONDRAF/NIRAS considers that B&C waste (as well as the other waste for which it is responsible) must be managed within a national framework and, therefore, on Belgian territory. Since Belgium decided in the 1960s to use nuclear energy to produce a large part of its electricity, and since the major part of Belgian radioactive waste originates from the nuclear fuel cycle, it is up to Belgium to ensure the management of its radioactive waste, regardless of its future energy policy. This position is in line with the recommendations and regulations in force at international level, which emphasise the responsibility of each country for the management of its own radioactive waste.

4.1.5 As soon as possible

Geological disposal ought to start as soon as possible, in light of the scientific, technical, societal and regulatory constraints to be taken into account. In other words, the pace of development and implementation of the disposal solution will have to be proportionate to its scientific and technical maturity, as well as to the public support it receives: programme dynamics will have to be maintained, but without taking any shortcuts.

Implementing geological disposal as soon as possible aims to

- enable ONDRAF/NIRAS to have a complete management system for B&C waste, which can be optimally organised, and thus to fulfil its mission;
- enable ONDRAF/NIRAS to assess the effective cost of disposal, and hence to apply the "polluter pays" principle on a concrete basis;
- ensure the maintenance of expertise and know-how at national level, in particular in the fields of waste knowledge, RD&D and assessment of disposal system performances, which makes an essential contribution to safety;
- minimise the burdens transferred to future generations and address the uncertainty for the municipalities on whose territory the waste is currently stored for a temporary, yet indefinite, period.

Since the development and implementation of a global geological disposal solution integrates scientific, technical, decision-making and societal aspects, the timing of the development and implementation programme cannot be established *a priori*, but will instead be determined gradually by a number of factors (RD&D evolution and results, building and maintenance of public support, siting process, content of the decisions made in the course of the decision-making process, etc.).

From a strictly technical point of view, in light of current knowledge, geological disposal of the first waste, which will be category B waste, cannot be envisaged before 2035–2040. It will take at least fifteen years to implement the necessary participative processes, to refine, confirm and optimise the recommended solution by means of RD&D activities, to strengthen societal support, especially through the siting process, and to prepare and submit the licence applications and then obtain the necessary licences, in particular the nuclear licence for "construction and operation" needed to start building the repository. It would take about fifteen years to build the repository.

4.2 Decision-making process

The development and implementation of the recommended technical solution fit into a decision-making process that integrates the technical and societal aspects. ONDRAF/NIRAS wishes this process to progress in steps, to be adaptable, participative and transparent, and to ensure continuity. It will run for approximately one hundred years from the moment a decision in principle is made, since decisions will have to be made at least until the closure of the repository.

ONDRAF/NIRAS has drafted a first outline of decision-making process, to serve as a basis for discussion, and to be improved, refined or modified through dialogue with all stakeholders. This dialogue, which ONDRAF/NIRAS intends to launch in the very near future, will start by identifying the stakeholders that will be taking part in the decision-making process. The dialogue process should help determine who will decide what, when, on what basis and how. With the exception of the provisions of the Law of 13 February 2006, there is currently in fact no normative system that describes how to complete the different steps between a decision in principle on the long-term management of radioactive waste and the nuclear licence application needed to implement the management solution chosen. Identification of such things as the key decisions to be made, the stakeholders taking part in the different steps of the decision-making process and their respective roles and responsibilities, and the documentation to be prepared, presents a major challenge. Dialogue, the financing of which also has to be organised, will help to begin to establish a participative process in the B&C programme, which up until a few years ago largely ignored this aspect.

The decision-making process should be included in the normative system to be established, which will have to provide ONDRAF/NIRAS and all stakeholders with whom it will cooperate with a sufficiently stable and well-defined framework for the development and implementation of the recommended technical solution.

The normative system to be established should include the creation of an independent monitoring body entrusted with the responsibility of ensuring that the decision-making process advances in completely documented steps, that it is adaptable, participative and transparent, and that it ensures continuity and integration of the societal and technical aspects.

4.3 Conditions arising from the consultations

ONDRAF/NIRAS considers that the development and implementation of the technical solution it recommends will have to meet conditions arising from the consultations, in addition to the applicable standards and regulations. These conditions result from concerns that are largely shared by the public and from concerns expressed by the official institutions consulted. Some of these conditions pertain to the development and implementation of a solution for the long-term management of radioactive waste and have been transposed by ONDRAF/NIRAS to the specific case of geological disposal (section 4.3.1), while other conditions have to do with the need to follow up developments regarding management possibilities that were examined in the Waste Plan but were discarded (section 4.3.2).

Other societal concerns, in particular the need for independent monitoring of the decision-making process, have been included in the technical solution and/or the decision-making process outlined by ONDRAF/NIRAS (section 4.2).

4.3.1 Conditions linked to the development and implementation of the recommended technical solution

In general, the public, whether or not it is in favour of a geological disposal solution, considers that it must be possible to retrieve the radioactive waste from the facility in which it has been placed, that it must be possible to control that the facility is functioning properly and is safe, and that knowledge of both the waste and the facility must be transferred from one generation to the next.

ONDRAF/NIRAS intends to take account of these requests in developing and implementing the geological disposal solution it recommends. *The scope of these requests will have to be further specified in dialogue with all stakeholders, taking into account the need to meet the requirements regarding safety and technical and financial feasibility.*

In this context, ONDRAF/NIRAS undertakes to

- ensure the reversibility of disposal during operation and examine the measures that could facilitate the possible retrieval of the waste after partial or complete closure of the disposal facility for a period that is yet to be defined. However, enhancing retrievability in the design and implementation of a disposal facility cannot occur at the expense of radiological safety, physical security and non-proliferation measures for nuclear materials (safeguards); enhancing retrievability could have an impact on the cost of the disposal facility;

- maintain the controls of the proper functioning of the repository, which will be performed in addition to regulatory controls, for a period that still has to be agreed with stakeholders. However, these controls cannot be performed at the expense of perturbing the system and thus its proper functioning;

- prepare in the most appropriate way the transfer of knowledge about the repository and the waste it contains to future generations. This transfer can be organised at both national and international level, in particular by means of the reports to be provided under international requirements. However, it is up to each generation to determine what knowledge and resources it wishes to transfer to the next generation.

4.3.2 Follow-up conditions

In parallel with the development and implementation of the geological disposal solution it recommends, ONDRAF/NIRAS will continue to follow up developments regarding management possibilities that were examined in the Waste Plan but were discarded. So it will continue to

- follow the evolution of knowledge on schistose formations on their own and as possible host formations, in order to maintain a fallback solution on Belgian territory if poorly indurated clays are eventually rejected;

- follow the evolution of knowledge on disposal in deep boreholes, in order to have, if needed, a solution for the long-term management of very limited amounts of waste, the retrieval of which one would like to make particularly difficult;

- follow, through international institutions, the evolution in the development of geological repositories shared by several European Union Member States, in order to understand policies on this matter and their possible impact on the Belgian programme;

- maintain a technology watch on national and international developments in the field of advanced nuclear technologies, although these technologies will not make any contribution to the long-term management of existing and planned conditioned waste. This technology watch is justified by the fact that, on the one hand, the policy for the management of commercial irradiated fuel from the current nuclear estate has not yet been determined and, on the other hand, the research facilities dedicated to advanced nuclear technologies will themselves generate waste that will have to be managed in the long term.

5 Proposals and recommendations on related issues the answers to which are not a matter solely for ONDRAF/NIRAS

Various issues, the answers to which are not a matter solely for ONDRAF/NIRAS, impact or will impact its management activities. They can be divided into two groups: issues relating to the long-term management of B&C waste, and issues concerning the development of one or more additional management systems. They are the subject of different proposals and recommendations.

5.1 Long-term management of B&C waste

In order to be able to fulfil its mission related to B&C waste management, ONDRAF/NIRAS must not only have confirmation of the solution it recommends for the long-term management of this waste, but it must also

- have a regulatory framework in place that is sufficiently clear and exhaustive for the geological disposal of B&C waste;
- be able to anticipate in a timely manner any variations in the volumes and types of B&C waste to be disposed of.

These issues are not a matter solely for ONDRAF/NIRAS.

As a result,

- *as far as the specific regulatory framework for geological disposal of B&C waste is concerned,*
  - ONDRAF/NIRAS would like this framework, which is currently being developed by FANC, to be available as soon as possible;
- *as far as the capacity of anticipating in a timely manner any variations in the volumes and types of B&C waste to be disposed of is concerned,*
  - ONDRAF/NIRAS recommends that the status (resource or waste) of irradiated nuclear fuel from commercial reactors be clarified;
  - ONDRAF/NIRAS recommends that the status (resource or waste) of the enriched fissile materials and plutonium-bearing materials excluding fuel held by some operators be clarified;
  - ONDRAF/NIRAS recommends that its opinion be sought in a timely manner by the competent authorities on all issues in which decisions likely to have a significant impact on radioactive waste management (for instance opting for the reprocessing of irradiated fuel, increasing fuel burnup, designing a major new nuclear facility, remediating a site with radioactive pollution) must be made.

However, the fact that a specific regulatory framework for geological disposal of B&C waste is not yet available, and the uncertainties about possible variations in the volumes and types of B&C waste to be disposed of through geological disposal do not call into question the need for a decision in principle and the possibility of making this decision.

5.2 Development of one or more additional management systems, in particular for radium-bearing waste

Since ONDRAF/NIRAS must ensure the long-term management of all radioactive waste on Belgian territory, it intends to be prepared to address different issues concerning substances that currently do not have radioactive waste status, but could acquire it later on. These issues concern existing situations for which radiological remediation decisions were made or are likely to be made by FANC. ONDRAF/NIRAS also intends to prepare itself to cope with the issue of long-term management of radioactive waste contained in licensed interim storage facilities for which no application has yet been submitted to ONDRAF/NIRAS to take charge of it. These issues essentially concern radium-bearing waste and waste from certain sectors of the non-nuclear industry — for instance the phosphate industry and the cement industry — which deal with naturally radioactive raw materials without the radioactive character being a desired property of these substances ("NORM" and "TENORM" waste).

The long-term management of radioactive waste resulting from future remediation and of radioactive waste contained in the licensed interim storage facilities will prompt ONDRAF/NIRAS to develop one or more management systems complementary to the existing system. These wastes are all long-lived, mainly of very low and low radioactivity levels, spread across numerous sites, and represent potentially considerable volumes.

In concrete terms, ONDRAF/NIRAS will in the coming years draw up a dedicated plan for the long-term management of radium-bearing waste that exists on the Umicore site in Olen and in the surrounding area, as well as of radium-bearing waste already in its storage facilities. This plan will aim to propose a long-term management policy for these wastes, which will provide the necessary framework for their optimal management, taking account of their specific characteristics. In order to develop a comprehensive plan, ONDRAF/NIRAS will, however, have to be informed by FANC about the general principles applicable to the long-term management of radium-bearing waste and to know in a timely manner FANC's position as to whether or not it is necessary to remediate the different landfill sites and grounds in Olen for which a decision is currently pending.

Moreover, if FANC decides that some other situations (situations pertaining to the NORM and TENORM issue or regarding the existence of old diffuse radioactive pollution on certain grounds) must be radiologically remediated, ONDRAF/NIRAS will examine the issue of this remediation in consultation with FANC, within the scope of a new management plan as the case may be.

The prospect of a plan for the long-term management of radium-bearing waste and, if need be, of one or more subsequent plans, does not call into question the considerations and findings concerning category B and category C wastes developed in the Waste Plan: this existing and planned waste can be managed in the long term within the scope of the global solution recommended by ONDRAF/NIRAS.

6 Waste Plan implementation

Commencement of the implementation of the Waste Plan, which was adopted by the ONDRAF/NIRAS Board of Directors on 23 September 2011, must be approved by a decision in principle from the Federal Government establishing a clear policy for the long-term management of B&C waste. This implementation will include a series of actions enabling the practical realisation of the long-term management solution chosen, such as the choice of a host formation, the choice of possible construction areas, the formalising of societal consultation processes and structures, the choice of one or several sites, the local integration of the solution, and the licence applications. The gradual development of this management policy will require the introduction of an appropriate normative system, which is currently lacking.

7 Link with the European "Waste" Directive of 19 July 2011

The global solution recommended in the Waste Plan for the long-term management of B&C waste, if approved by a decision in principle, will contribute to fulfilling several requirements of the European "Waste" Directive of 19 July 2011 establishing a community framework for the responsible and safe management of spent fuel and radioactive waste. The recommended solution is in line with the principles of the Directive, in particular the national responsibility for waste management, the fact that safety in the long term requires a facility that ensures safety in a passive way, the "polluter pays" principle, the intergenerational equity principle, which requires current generations to avoid transferring undue burdens to future generations, and the establishment of a documented and participative decision-making process. The recommended solution is that which the Directive considers to be *"the safest and most sustainable option as the end point of the management of high-level waste and spent fuel considered as waste"*.

The Waste Plan as such serves as a preparatory document for the first Belgian national programme, which will have to be notified to the Commission by 23 August 2015 at the latest and will have to cover all stages of the management of irradiated fuel and radioactive waste.

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Part 1

Context and scope of the Waste Plan

1 The Waste Plan in a few words

Radioactive waste: "any material for which no use is foreseen and which contains radionuclides in concentrations in excess of those that the competent authorities consider permissible in materials suitable for use or discharge without control" (RD of 30 March 1981, article 1)

Activity: means the rate at which transformations occur in a radioactive material

In Belgium, the legislature entrusted the management of radioactive waste* [1] to a public institution with legal status created for this purpose in 1980: the Belgian Agency for Radioactive Waste and Enriched Fissile Materials or ONDRAF/NIRAS ([1, 2] as amended, principally by [3, 4, 5, 6]). This management must ensure the protection of man and the environment against the risks associated with this waste, and therefore includes an important long-term component. Conditioned short-lived low-level and medium-level waste, called category A waste, presents in fact a risk for man and the environment on a timescale of hundreds of years. A common feature shared by the other conditioned wastes managed by ONDRAF/NIRAS, namely those from categories B and C, also called B&C waste, is that they also present a risk, but on a timescale of tens to hundreds of millennia owing to the quantities of long-lived radionuclides that they contain. B&C waste is high-level and/or long-lived waste.

The long-term management of radioactive waste is under the exclusive competence of ONDRAF/NIRAS. In accordance with the legal framework, this long-term management must ensure that the waste is disposed of in a long-term management facility without intention to retrieve: in other words, it must provide a solution that *can become definitive* (article 1 of the Royal Decree of 30 March 1981 [2]). However, the fact that the waste is not intended to be retrieved does not necessarily preclude retrieval or controls.

Contrary to the situation for category A waste (section 4.2.3), no institutional policy has yet been formally approved in Belgium for the long-term management of B&C waste. The relevance and the quality of research, development and demonstration (RD&D) activities in the field, initiated in 1974 by the Belgian Nuclear Research Centre (*Studiecentrum voor Kernenergie / Centre d'Etudes de l'Energie Nucléaire* or SCK•CEN) and with the responsibility transferred to ONDRAF/NIRAS a decade later, have been confirmed several times since 1976 by different commissions and working groups asked by institutional bodies to give an opinion on ongoing studies concerning long-term management of B&C waste or on energy policy issues. However, the direction taken — *geological disposal in poorly indurated clay* (in Belgium, Boom Clay or Ypresian Clays) —

[1] The words marked with an asterisk are defined in the Belgian legal and regulatory framework and appear in a glossary at the end of the Waste Plan. They are also given, along with other words, in insets in the margin of the text the first time that they appear. Several current inconsistencies in the terminology used in the legal and regulatory framework are subject to consultation.

Half-life: means the time needed for the level of activity of a radionuclide to reduce by one half through the process of radioactive decay

Irradiated fuel: "fissile or plutonium-bearing materials contained within a structure that allows their use in a reactor, after their definitive unloading from the reactor" (RD of 30 March 1981, article 1)

Excess quantities: "quantities of enriched fissile materials, plutonium-bearing materials or fresh or irradiated fuel for which no use or subsequent transformation is planned by the producer or operator" (RD of 30 March 1981, article 1)

has not been *formally* confirmed or refuted at federal level (section 8.1.1). An institutional policy for long-term management is essential for many reasons, in particular to enable ONDRAF/NIRAS to optimise various aspects of its short-term and medium-term management system and, more broadly, to enable it to fulfil its public service mission, to address the current uncertainty relating to storage duration in the municipalities where this waste is currently stored temporarily, and to avoid passing on the management responsibility, including associated burdens, to future generations.

1.1 Motivation and objectives of the Waste Plan

Insofar as

- ONDRAF/NIRAS is legally bound to have a general programme for the long-term management of radioactive waste (article 2, § 3, 1. c, of the Royal Decree of 30 March 1981 [2]);
- the Law of 2 August 2002 [7], transposing the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, signed in Vienna in 1997 [8], requires Belgium to have a long-term management policy for its radioactive waste;
- the European Directive 2001/42/EC of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment [9] introduces the legal concept of plans and programmes drafted with a view to their adoption by the Parliament or Government;
- there is not yet an institutional policy regarding the long-term management of B&C waste in Belgium;
- a long-term management policy for B&C waste is *necessary* (section 5.2);
- the ONDRAF/NIRAS RD&D programme for long-term management of B&C waste, which is in line with international recommendations, has attained an advanced level of technical maturity (chapter 8) [10], which renders *possible* a general policy decision in this field;
- ONDRAF/NIRAS in 2004 was entrusted by its supervisory authority to prepare and start societal dialogue at all levels on the long-term management of B&C waste and to assess all possible strategies for this management in order to enable a decision on the management solution to be implemented [11];
- the Law of 13 February 2006 relating to the assessment of the environmental impact of certain plans and programmes and to public participation in drawing up plans and programmes relating to the environment [12] makes the link between the obligation of ONDRAF/NIRAS to have a general programme for the long-term management of radioactive waste and
    - European Directive 2001/42/EC, by requiring that this general programme be subject to an environmental assessment and that this assessment (strategic environmental assessment or SEA) include an evaluation of the likely impacts of "reasonable alternative solutions";
    - European Directive 2003/35/EC providing for public participation in the drawing up of certain plans and programmes relating to the environment [13];

ONDRAF/NIRAS has taken the initiative to compile in a single document, the *Waste Plan*, all elements necessary to enable the Government to make, with full knowledge of the facts, a *decision in principle*, i.e. a *general policy decision* or *general guidance decision*, relating to the long-term management of B&C waste, including non-reprocessed irradiated* nuclear fuel declared (or likely to be declared) as waste, as well as excess quantities* of enriched fissile materials* and plutonium-bearing materials* declared (or likely to be declared) as waste.

In the rest of the text, the phrase "B&C waste" must be understood as also referring to non-reprocessed irradiated nuclear fuel declared (or likely to be declared) as waste, as well as excess quantities of enriched fissile materials and plutonium-bearing materials declared (or likely to be declared) as waste.

The Waste Plan thus focuses on the long-term management of B&C waste, considering only existing and planned (mainly within the scope of the current nuclear power programme) waste. (It does not therefore consider the long-term management of waste from the possible operation of new reactors.) The long-term management of category A waste is mentioned in the Waste Plan for the record, since the management solution to be implemented for this waste — a surface disposal facility in the municipality of Dessel — was decided by the Council of Ministers on 23 June 2006 [14]. Finally, the Waste Plan does not propose a strategy for the long-term management of radioactive waste from past and future remediation operations. For situations where a remediation decision has been made by the safety authority (Federal Agency for Nuclear Control or FANC), ONDRAF/NIRAS and FANC and regional bodies still need to develop a joint vision regarding the long-term management of the radioactive waste that will result from these remediation operations. For other situations likely to require remediation, it is FANC's responsibility to express an opinion on the need for remediation. However, the Waste Plan identifies a series of related issues (including issues relating to remediation), the answers to which are not a matter solely for ONDRAF/NIRAS, but are likely to affect its activities and in particular the long-term management of B&C waste. That said, these issues do not call into question the need for a decision in principle as soon as possible and do not impact the management solution for B&C waste recommended by ONDRAF/NIRAS, namely *geological disposal in poorly indurated clay (Boom Clay or Ypresian Clays) in a single facility (i.e. for all B&C waste and built at a single site) located on Belgian territory, as soon as possible, but with the pace of development and implementation of the solution needing to be proportionate to its scientific and technical maturity, as well as its societal support.* (The start of disposal operations cannot be envisaged before 2035–2040, given the scientific, technical, societal and regulatory constraints to be taken into account.)

In addition to the Waste Plan, the general programme for long-term management of radioactive waste provided for by the Royal Decree of 30 March 1981 will ultimately include one or more other dedicated plans covering the management of all substances that have or will have radioactive waste status. These plans will be established as the corresponding issues become sufficiently mature. So, in future years, ONDRAF/NIRAS will draw up a plan relating to the long-term management of the significant volumes of radium-bearing waste from past activities that are present on Belgian territory and which constitute a particular issue (section 11.1). The prospect of such a plan does not call into question the considerations and conclusions relating to category B waste (some of which is radium-bearing waste) and category C waste developed in the current Waste Plan.

Enriched fissile materials: "any materials containing fissile isotopes of uranium in greater quantities than natural uranium and being found in a form other than that of fresh or irradiated fuel" (RD of 30 March 1981, article 1)

Plutonium-bearing materials: "any materials containing fissile isotopes of plutonium and being found in a form other than that of fresh or irradiated fuel" (RD of 30 March 1981, article 1)

As a decision-making tool intended to support the Waste Plan and the decision in principle that it is aiming for, the SEA focuses solely on the long-term management of B&C waste [15]. Indeed, the choice of the long-term management solution for category A waste was subject to the necessary institutional decisions (section 5.1). The SEA is a document by a contractor — *Resource Analysis* (known as TRITEL since June 2010) — which ONDRAF/NIRAS has ascertained, in accordance with article 9 of the Law of 2006, to have no interest in the Waste Plan.

According to ONDRAF/NIRAS, the decision in principle that the Waste Plan must allow should focus on the following three aspects:

- *the type of solution to be developed for the long-term management of B&C waste;*
- *the decision-making process, including the principal milestones and a timetable, to be followed for implementation of the chosen solution;*
- *how to obtain and maintain the societal support necessary for the progressive implementation of the chosen solution.*

Such a decision in principle is not therefore an immediate decision on a specific solution at a given site, but would be the first step in a progressive and adaptable decision-making process. Indeed, by definition, it is a *decision made in the presence of uncertainties* and it therefore has a *conditional element* to it: it must be confirmed and further specified through successive decisions during the decision-making process, demonstrating that the solution can be implemented in such a way that it satisfies safety requirements, is technically and financially feasible, and is acceptable to society. It will take at least one to two decades from selecting the type of solution to be developed to starting the industrial activities themselves. This period should notably be used not only to confirm and refine the technical and scientific knowledge by continuing RD&D, which will gradually change in nature as it evolves towards confirmation of that knowledge, and preparing for the industrial phase and the licence application files, but also to develop sufficient societal support for the selected solution and for the site selection process. The decision-making process should be reflected in a normative system, which is currently lacking.

1.2 Developing the Waste Plan

Since ONDRAF/NIRAS wanted to provide the Government with all the elements needed to make a fully informed decision in principle relating to the long-term management of B&C waste, and because it was the first time that public opinion would formally be sought on this subject, via the consultation procedure provided for by the Law of 13 February 2006, ONDRAF/NIRAS elected to conduct an assessment of the possible management options and a societal consultation broader than those required by law. In view of this, it made the following choices.

- The Waste Plan and the SEA on which it is based considered all possible options for the management of B&C waste *in the broadest possible way*, including options rejected internationally and options that cannot become definitive, as well as the option that involves maintaining the current situation (status quo).
- The societal consultation was not limited to the public consultation provided for in law. Insofar as the long-term management of radioactive waste represents a significant issue for society, ONDRAF/NIRAS wanted to involve the population in

developing the document preceding the Waste Plan, the "draft Waste Plan", and the SEA, through a *societal consultation*, which was conducted well before the legal public consultation procedure. The issue of the long-term management of radioactive waste, and particularly of B&C waste, is in fact not restricted to the scientific and technical challenge, but also comprises a societal aspect and generates various concerns: Who ensures the long-term safety of the solution being considered? What is its long-term impact on the environment? Can it be financed? By whom is it financed or by whom will it be financed? What burdens will it place on future generations? How can we ensure continuity and knowledge transfer from one generation to the next? Are the scientific grounds sound enough? Do we have a good understanding of the techniques needed to implement it?...;

- The assessment of these options within the scope of the SEA was not limited to environmental impacts, but included, as far as practicable, the environmental and safety, technical and scientific, financial and economic, and societal and ethical aspects (Inset 1). The SEA is therefore an expanded or *integrated* SEA.

Since the Waste Plan aims for a strategic decision, as opposed to a decision relating to a specific project, the Waste Plan and SEA have considered the management options in generic terms, i.e. without linking them to a particular site. They therefore neither address siting issues nor, *a fortiori*, facility design. Consequently, the option assessment exercise was mainly qualitative, relying on expert judgement based on the knowledge (entirely open) available at national and international level and, insofar as possible, on similar studies abroad and the consequent decisions, as well as on feedback from existing similar facilities in Belgium and abroad. However, quantitative analyses were carried out whenever possible and appropriate. Due also to the strategic nature of the Waste Plan, transboundary environmental impacts were not assessed.

Inset 1 – The four aspects of a sustainable solution for the long-term management of radioactive waste

On publishing the SAFIR 2 report [16, 17], which summarised the scientific and technical knowledge in terms of developing a solution for the long-term management of B&C waste in Belgium, and based on the experience that it was building in involving local communities in the disposal project for category A waste, ONDRAF/NIRAS had highlighted the unsuitability of an approach based essentially on the concepts of scientific evaluation of risk and prevention, when a decision has to be made in a situation where there are many uncertainties [18]. In this type of situation, which is that of the long-term management of B&C waste, the choice of the type of solution to be used, which must of course be based on sound scientific and technical arguments, indeed takes on a societal aspect. In addition to the technical and scientific aspect, the decision-making process must therefore take into account the values that prevail in society.

The concept of a sustainable solution

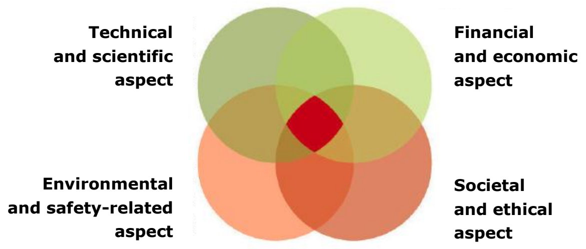
The concept of sustainable development first appeared in and is central to the report *"Our Common Future"*, also called the "Brundtland Report" [19]. Published in 1987 by the World Commission on Environment and Development of the United Nations, this report establishes an unequivocal connection between economic growth, environmental issues, poverty and development. Sustainable development is considered as a development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It is therefore based on an awareness of duty towards future generations. The concept of sustainable development, along with those of intragenerational and intergenerational equity, have subsequently been reiterated within the framework of the principles laid down in the United Nations Declaration on Environment and Development made in Rio de Janeiro in 1992 [20].

Some of the most notable principles and concepts associated with sustainable development include the precautionary principle, long-term vision, the "polluter pays" principle, societal responsibility and the commitment not to pass unacceptable burdens on to other populations (particularly the less privileged populations) or future generations [21]. With the adjective *sustainable* frequently being used to qualify words other than *development* and likely to lead to confusion, it is useful to specify its meaning in the context in which it is used [21].

Belgium is committed to the process of sustainable development following its adoption of the Law of 5 May 1997 on the coordination of the federal policy of sustainable development [22].

ONDRAF/NIRAS believes that the solutions for the long-term management of B&C waste must be integrated solutions, that is, solutions that ensure the protection of man and his environment, are based on a balanced consideration of the technical, economic and societal aspects, and are drawn up in dialogue with all stakeholders. These solutions are called "sustainable" in the sense that they consider the three aspects inherent to sustainable development — the environment, man, and prosperity (which includes not only economic benefits, but also benefits to society) [23] — as well as the scientific and technical aspect. The latter applies to the other aspects as well: it is the basis for developing the management options and assessing not only their environmental and economic impact, but also their impact on society and the reliability of this assessment.

In order to give some practical meaning to the concept of sustainable development, ONDRAF/NIRAS elected to assess the management options being considered against the following four aspects.



According to a recent study by the Free University of Brussels (*Vrije Universiteit Brussel* or VUB) for the *Belgian Science Policy Office* (BELSPO) [24], the approach of ONDRAF/NIRAS in its Waste Plan *"is a rather revolutionary approach for nuclear culture and the only approach framed within sustainability criteria up to now"*.

Technical and scientific advances are recognised as one of the bases for sustainable development in general [21], and its environmental aspects in particular. This was indicated in the Agenda 21 programme *"A Blueprint for Sustainable Development"* adopted by the United Nations Conference on Environment and Development in Rio de Janeiro in 1992; chapter 22 confirms the importance of promoting safe and environmentally sound management of radioactive waste [25].

Furthermore, the economic, financial and societal aspects, which refer in particular to the need to ensure financing for waste management without passing on undue burdens to future generations, are an integral part of the basic principle of optimisation of the radiological protection of man and the environment (also known as the ALARA — as low as reasonably achievable — principle). The ALARA principle stipulates that the probability of exposure, the number of people exposed and the size of their individual doses should be kept as low as possible, taking into account economic and social factors [26].

The need to consider and integrate the four aspects of a sustainable solution in assessing the options considered for the management of B&C waste was highlighted both by participants in the ONDRAF/NIRAS dialogues and at the interdisciplinary conference organised by ONDRAF/NIRAS prior to writing the draft Waste Plan and the SEA [29], and by those who attended the citizens conference independently organised by the King Baudouin Foundation [31]. According to the VUB study [24], *"A rather high attention is given to integration (multidisciplinary, techno-economic social and ethical). Within the NIRAS waste plan, principles and mechanisms for the related equity dimensions were considered in a transparent and participative exercise while the initiative for assessment was delegated to an institute of high authority (the King Baudouin Foundation) with experiences in participative experiments, and having no links with the nuclear sector (independent)"*.

A sustainable development approach would, strictly speaking, require at least a global approach at the level of the practices that generate radioactive waste, as provided for in the application of the first principle of radiation protection (the justification principle — Inset 6 in section 4.1.3) [57, 58], in particular, the use of nuclear energy to produce electricity, which is outside the competence of ONDRAF/NIRAS.

Sustainable development and the precautionary principle

The Rio Declaration connects the concept of sustainable development to the precautionary principle (principle no. 15), which makes the link between risk-taking situations in the presence of great uncertainty and the scientific and technical aspect: *"In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."* In its meaning of principle of action, which can be interpreted as "if in doubt, do everything to act for the best" [27], the precautionary principle involves in particular [27, 28]:

- multidisciplinary scientific expertise (uncertainty is not necessarily synonymous with the absence of knowledge, but acknowledges complex situations where the consequences extend over the long term), which assumes the implementation of research and development programmes to analyse the risks incurred and attempt to minimise them and assess the alternatives;
- a dialogue which is as broad and as early as possible with all stakeholders, including the public, on the risks incurred, their assessment and their acceptability;
- a periodic reassessment of the risks and uncertainties as knowledge evolves.

This interpretation is consistent with the approach by ONDRAF/NIRAS, which is faced with managing an environmental problem which is far beyond usual environmental scopes and timescales. The ONDRAF/NIRAS Waste Plan and the SEA on which it is based assess the risks and identify the scientific and societal uncertainties related to the different options considered for the management of B&C waste. Their content has been enhanced as a result of several consultation initiatives with society. ONDRAF/NIRAS will periodically reassess the risks and uncertainties associated with the chosen solution, as it is developed.

The Waste Plan and the SEA are the result of a multi-step development process governed by a legal procedure (section 1.2.2) and preceded by a societal consultation organised on the initiative of ONDRAF/NIRAS (section 1.2.1) (Figure 1).

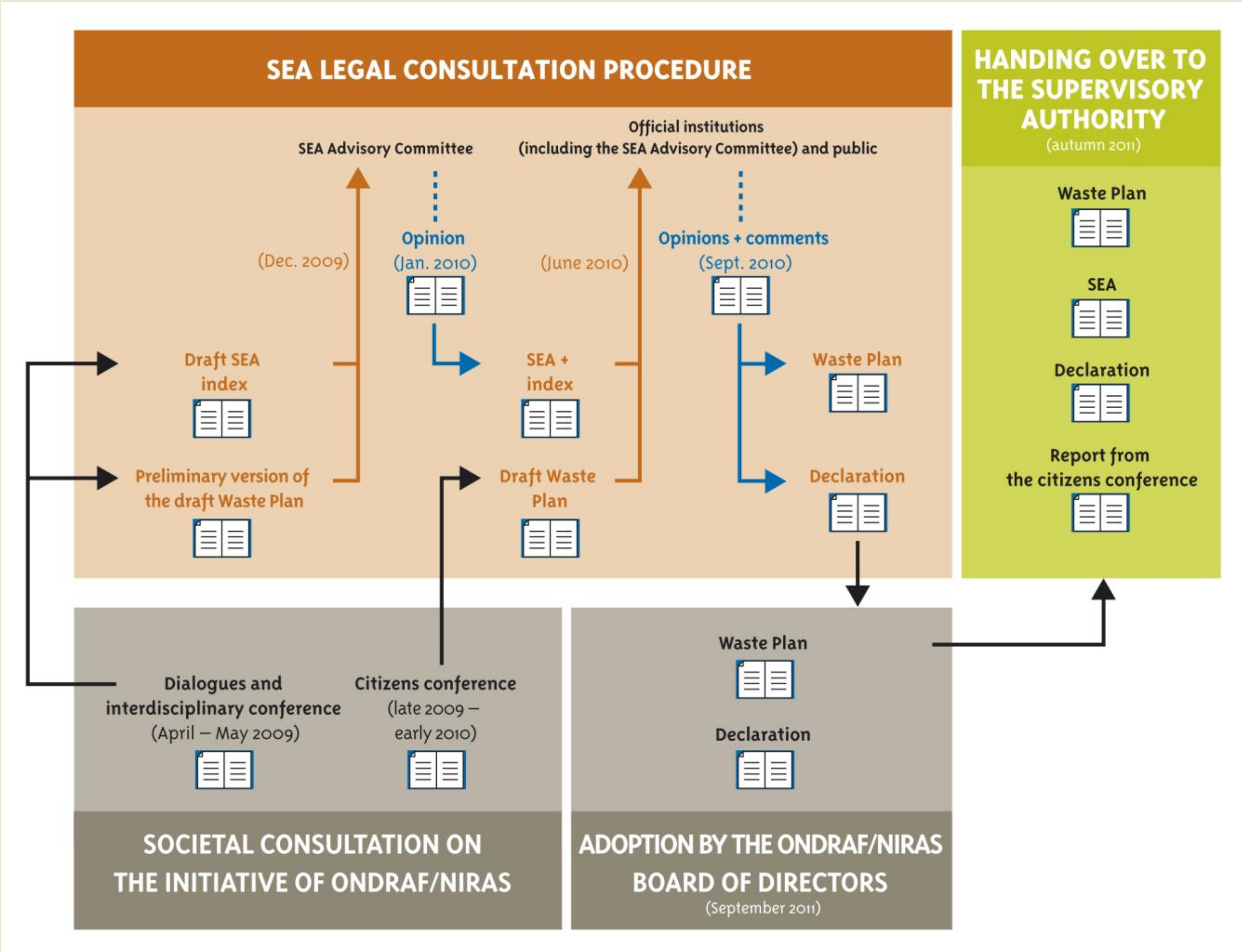


Figure 1 – The societal consultation organised on the initiative of ONDRAF/NIRAS and the legal consultation procedure, followed by adoption by the ONDRAF/NIRAS Board of Directors, then the handing over of documents to the supervisory authority.

1.2.1 Societal consultation organised on the initiative of ONDRAF/NIRAS

The societal consultation organised on the initiative of ONDRAF/NIRAS comprised two parts (Figure 1 and Figure 2).

- In April and May 2009, a series of *ONDRAF/NIRAS dialogues* and an *interdisciplinary conference* provided an opportunity for organisations from civil society, experts and interested citizens to express their concerns and expectations with regard to the long-term management of B&C waste. The communication campaign relating to this consultation notably included a press conference, a first dispatch of 4 500 emails, the subsequent dispatch on two occasions by an agency specialising in online surveys of 30 000 emails inviting recipients to consult the ONDRAF/NIRAS dedicated website (www.ondraf-plandechets.be) and register for the dialogues, a telephone campaign to 200 organisations from civil society, and the publication on 15 instances of an advert in free newspapers.

The eight days of dialogue brought together around 60 participants, with the interdisciplinary conference involving 84 experts from different disciplines, including disciplines not directly connected with radioactive waste management. These days of reflection were led by independent (from ONDRAF/NIRAS) facilitators. The role of ONDRAF/NIRAS was limited to providing the necessary information to participants and observing the discussions.

- A *citizens conference*, which was organised in late 2009 – early 2010 by the King Baudouin Foundation on behalf of ONDRAF/NIRAS, focused on decision-making about long-term management of B&C waste. Independently of ONDRAF/NIRAS, the King Baudouin Foundation formed a panel of 32 citizens, representative of our diverse society, and over three weekends facilitated their considerations on this subject. ONDRAF/NIRAS was not involved in this process.

Figure 2 – Societal consultation organised on the initiative of ONDRAF/NIRAS. Left, a working group during the interdisciplinary conference (source: Dialogue Learning Centre); right, the presentation of the final report by the participants in the citizens conference organised by the King Baudouin Foundation to the General Manager of ONDRAF/NIRAS (source: King Baudouin Foundation; photograph: Emmanuel Crooÿ).

The results of the societal consultation organised on the initiative of ONDRAF/NIRAS were taken into account when drawing up the SEA and the draft Waste Plan and, therefore, in the Waste Plan itself. Reports of the ONDRAF/NIRAS dialogues, along with the summary [29] of these reports and the interdisciplinary conference, all written by the independent facilitators, are available on the ONDRAF/NIRAS dedicated website, along with the report by the review committee [30], also made up of independent individuals who acted as observers during the consultation. The report from the citizens conference [31] is available on the King Baudouin Foundation website (www.kbs-frb.be).

1.2.2 Legal consultation procedure

In accordance with the provisions of the Law of 13 February 2006, the Waste Plan and SEA are the culmination of a multi-step development process (Figure 1).

First, ONDRAF/NIRAS submitted a draft SEA index to the Advisory Committee set up by the Law of 2006 (called the "SEA Advisory Committee" in the rest of this document), containing the environmental impacts to be examined and the methodological aspects of the assessment. The SEA Advisory Committee had to verify the compliance of the index, in terms of content and approach, with the legal requirements. The draft SEA index was accompanied by a preliminary version of the draft Waste Plan intended for the SEA Advisory Committee.

Second, ONDRAF/NIRAS submitted its draft Waste Plan and the SEA (Figure 3) for an opinion to the SEA Advisory Committee, the Belgian Federal Council for Sustainable Development, the Governments of the Regions and, as provided for by law, to FANC. At the same time, it submitted the same documents for public consultation.

Figure 3 – The draft Waste Plan, the SEA and the non-technical summary of the SEA submitted for legal consultation.

The public consultation was announced 15 days before it began by a notice in the Belgian Official Journal [32], on the federal portal website, on the national portal website for the Aarhus Convention, on the ONDRAF/NIRAS dedicated website, and in a dozen of the major daily papers (six Dutch language papers, five French language papers and one German language paper) representing a circulation of approximately 1 770 000 copies (Figure 4). The draft Waste Plan and the SEA were available in French, Dutch and German. They could be downloaded from the ONDRAF/NIRAS dedicated website and were available in printed format upon request. Furthermore, ONDRAF/NIRAS provided all municipalities in Belgium with the option of having one or several copies of the draft Waste Plan and the SEA so that they could make them available to their constituencies. Finally, on its own initiative, ONDRAF/NIRAS informed the official SEA representatives from the European Union Member States of the consultation and invited them to provide comments from their countries.

Figure 4 – French version of the announcement of the public consultation published in the French language daily press on 20 May 2010.

In its opinion [33] on the draft Waste Plan and the SEA, the SEA Advisory Committee did not identify any deficiencies regarding the way in which the legal procedure was implemented. It *"appreciates the investment that ONDRAF/NIRAS has made to ensure the correct implementation of the environmental assessment procedure, particularly by producing a version of the index that takes its comments into account."* It also noted that *"The documentation is complete […]."* [translation ONDRAF/NIRAS]

The SEA Advisory Committee also confirmed that an assessment of transboundary environmental impacts was not yet possible.

> *"The Committee considers that, in view of its general content, the draft Waste Plan does not allow the determination at this stage of whether its implementation is likely to have a non-negligible impact on the environment of another European Union Member State or another State party to the Espoo Convention of 25 February 1991 on the assessment of the environmental impact in a transboundary context. Nevertheless, the Committee draws the attention of the authors of the Waste Plan to the fact that future decisions about the management of nuclear waste in Belgium, and especially the location of facilities, could involve transboundary consequences that will have to be taken into account, in accordance with the legislation in force."* [translation ONDRAF/NIRAS]

Third, in finalising the Waste Plan, ONDRAF/NIRAS took into account the opinions of the official institutions and the comments provided by the public during the legal consultation procedure. In particular, it had to supplement the solution that it recommends for the long-term management of B&C waste with conditions in terms of the retrievability of the disposed waste, controlling that the disposal system functions correctly, and knowledge transfer relating to the repository, conditions for which the exact scope will be defined in dialogue with all stakeholders. Other concerns, in particular following up of developments regarding management possibilities that were examined in the Waste Plan but were discarded and the need for independent monitoring of the decision-making process, have been incorporated into the global solution recommended. In accordance with the provisions of the Law of 2006, ONDRAF/NIRAS also issued a declaration [34] which among other things summarises the way in which the SEA, as well as the opinions and comments received, were taken into account in finalising the Waste Plan. The Law of 2006 does not, however, allow for changing of the SEA based on these opinions and comments.

The Waste Plan was adopted by the ONDRAF/NIRAS Board of Directors, the only authority entitled to do so [2], on 23 September 2011.

[2] The Law of 13 February 2006 does not aim to establish the rules for the adoption of plans or programmes to which it applies. One should thus refer to the particular regulations relating to the terms for the development and adoption of plans and programmes. In this respect, the Law of 13 February 2006 indicates that these plans and programmes must be provided for in the regulations for it to be applied (in the case of the ONDRAF/NIRAS Waste Plan, article 2, § 3, 1. c, of the Royal Decree of 30 March 1981, as amended, providing for a long-term management programme). It is therefore the regulation coordinating the functioning of ONDRAF/NIRAS, as well as the execution of its missions, that determines the authority entitled to adopt the Waste Plan.

1.2.3 Handing over to the supervisory authority

The Waste Plan as adopted is handed over by ONDRAF/NIRAS to its supervisory authority, accompanied by the declaration, the SEA and the report from the citizens conference. In this way, the Government will have all the elements needed to make a decision in principle regarding the long-term management of B&C waste. Indeed, ONDRAF/NIRAS considers that the Waste Plan as adopted can only be implemented through Government approval.

1.3 Structure of the Waste Plan

The Waste Plan is structured in four parts.

- The *first part* places the Waste Plan in context, justifies its scope and emphasises the *need* for a decision in principle as soon as possible for the long-term management of B&C waste.
- The *second part* goes into detail about the issue of the long-term management of B&C waste and shows that a decision in principle *can be made*. It succinctly describes the different management options considered and the methodological approach followed in the SEA for their assessment. It then summarises this assessment according to the principles and criteria that appear most relevant in guiding a decision in principle. Finally, it describes in broad lines the management solution recommended by ONDRAF/NIRAS and the participative decision-making process outlined for its gradual implementation, including the elements relating to the way in which to establish and maintain societal support for this solution.
- The *third part* is intended to attract the Government’s attention to a series of related issues, the answers to which are not a matter solely for ONDRAF/NIRAS.
- Finally the *fourth part* summarises the solution recommended by ONDRAF/NIRAS for the long-term management of B&C waste, including the conditions accompanying it. It also formulates various recommendations for the aforementioned related issues.

In the annexes, the Waste Plan contains the following: an outline of the origins and characteristics of existing and planned (mainly within the scope of the current nuclear power programme) B&C waste; a summary of the key points in the European Directive of 19 July 2011 for the responsible and safe management of spent fuel and radioactive waste directly related to the Waste Plan and a first analysis of the Waste Plan’s contribution to compliance with the Directive’s requirements; a glossary of terms defined in the Belgian legal and regulatory framework; and a list of acronyms.

2 ONDRAF/NIRAS

ONDRAF/NIRAS is the public institution with legal status created in 1980 by the legislature to *manage* radioactive waste present on Belgian territory whatever its origin and provenance [3] ([1, 2] as amended, principally by [3, 4, 5, 6]). The report to the King which led to the Royal Decree of 1981 specifies that *"The fundamental concern that led to the establishment of the institution is therefore to provide, without any profit-making aims, the management of operations involving nuclear materials in a way that is as rational, coordinated and uniform as possible. […] The legislature wanted this management to be conducted by a single body under public control in order to guarantee that public interest can prevail in all decisions to be made in this area."* [translation ONDRAF/NIRAS]

Radioactive substance: "any substance containing one or several radionuclides, the activity or concentration of which cannot be ignored for radiation protection reasons" (Law of 15 April 1994, article 1)

2.1 Legal mission for radioactive waste management

Under the Law of 8 August 1980 (Inset 2) [1], ONDRAF/NIRAS is responsible for managing all radioactive waste [4], whatever its origin and provenance, and establishing an inventory of all nuclear facilities and sites containing radioactive substances*. (This inventory mission is known as the "nuclear liabilities inventory mission".) The Law of 8 August 1980 also made ONDRAF/NIRAS responsible for certain other missions, particularly in the field of management of enriched fissile materials, plutonium-bearing materials and irradiated fuel.

The missions in terms of radioactive waste management mainly include the following: transport outside the producers' facilities; treatment and conditioning*, for producers who do not have facilities approved by ONDRAF/NIRAS for this purpose; storage* outside the producers' facilities; and disposal* (or final storage) which, according to the legal definition [7], designates the emplacement of irradiated fuel or radioactive waste in an appropriate facility *without intention to retrieve.* (However, the fact that waste

3 The legal framework defining the missions of ONDRAF/NIRAS and the way in which it operates is established in article 179, § 2, of the Law of 8 August 1980 regarding the budgetary proposals 1979–1980 and its Royal Decree dated 30 March 1981, including their respective successive amendments, in particular the Law of 11 January 1991, the Royal Decree of 16 October 1991, the Law of 12 December 1997 and the Law of 29 December 2010.

4 The Royal Decree of 30 March 1981 specifies that it relates to radioactive waste present on Belgian territory (art. 2, § 2, 1).

Treatment and conditioning of radioactive waste: "series of mechanical, chemical, physical and other operations designed to convert radioactive waste into packages that satisfy operational requirements for handling, transport, storage or disposal" (RD of 30 March 1981, article 1)

Storage of radioactive waste: "temporary storage of such waste with the intention and possibility of subsequent recovery" (RD of 30 March 1981, article 1)

Disposal (or final storage): "emplacement of spent fuel or radioactive waste in an appropriate facility without intention to retrieve" (Law of 2 August 2002, article 2)

retrieval is not intended does not necessarily preclude retrieval or controls.) In other words, ONDRAF/NIRAS must develop and implement a *closed* management system for all radioactive waste of which it has taken and will take charge*, i.e. a management system where the last step is identified and constitutes the final destination for this waste (see chapter 4 for a description of the management system developed by ONDRAF/NIRAS).

The Royal Decree of the Law of 8 August 1980 — the Decree of 30 March 1981 — also specifies in article 2 [2] that ONDRAF/NIRAS must in particular

- establish and update the inventory of existing radioactive waste and forecasts for waste production;
- establish and update a general long-term management programme for radioactive waste, including a technical and economic description of the actions it envisages for the programme;
- based on the general rules proposed to and approved by the competent authorities, establish acceptance criteria for conditioned and non-conditioned waste that it must take charge of;
- approve the facilities intended for treatment and conditioning of radioactive waste;
- ensure that the quality of the conditioned or non-conditioned radioactive waste complies with the acceptance criteria, and carry out its final inspection*.

In order to be successful, radioactive waste management, which constitutes the core of the ONDRAF/NIRAS mission, must form part of a long-term *management policy*. ONDRAF/NIRAS does not define this policy, but it can make proposals to its supervisory authority, which subsequently decides on further action, and provide it with elements for consideration. ONDRAF/NIRAS may also take the initiative to submit institutional policy points that concern radioactive waste management and which must be clarified so that it can fulfil its mission.

ONDRAF/NIRAS is not competent in a series of matters that may impact radioactive waste management, such as Belgium's future policy in terms of electricity production and especially electricity from nuclear power, the issue of reprocessing of irradiated nuclear fuel, the commercial choices of companies that generate radioactive waste, the general policies of research institutions, the granting of nuclear licences for the construction and operation of nuclear facilities, remediation decisions in the event of radioactive pollution, and the development of regulations in terms of radiation protection.

Inset 2 – Extracts from article 179, § 2, of the Law of 8 August 1980 as amended [1] [translation ONDRAF/NIRAS]

"2° […] the organisation is responsible for

- the management of all radioactive waste, irrespective of its origin and provenance,
- establishing an inventory of all nuclear facilities and all sites containing radioactive substances, as defined by article 1 of the Law of 15 April 1994 on the protection of the population and the environment against the hazards of ionising radiation and establishing the Federal Agency for Nuclear Control,

along with certain missions in the field of

- enriched fissile materials, plutonium-bearing materials and irradiated fuel management,
- and the decommissioning of closed nuclear facilities."

"3° The organisation can only manage foreign waste after receiving the agreement of its supervisory authority."

"4° The missions relating to radioactive waste include transport outside the facilities, treatment and conditioning for producers who do not have facilities approved by ONDRAF/NIRAS for this purpose, storage outside the facilities, and disposal, along with the collection and assessment of all the information needed to perform the aforementioned missions. Furthermore, the organisation is entitled to take any action or measure intended to create and maintain the necessary societal support to ensure the integration of a radioactive waste repository in a local community."

"6° The mission relating to the inventory includes the establishment of a location and status index for all nuclear facilities and all sites containing radioactive substances […]."

"8° The missions relating to enriched fissile materials, plutonium-bearing materials and irradiated fuel are transport, outside the facilities, of the enriched fissile and plutonium-bearing materials in quantities and enrichment rates exceeding the limits defined by the King, storage outside the facilities of plutonium-bearing materials that are in excess of the operational needs of the facility, storage, outside the facilities, of irradiated fuel or fresh fuel that has no planned use, as well as the collection and assessment of all the information needed to perform the aforementioned missions."

Taking charge: "set of technical and administrative operations for collection of radioactive waste or excess quantities from producer sites and their transfer to the facilities managed by the Organisation" (RD of 30 March 1981, article 1)

Inspection: "operation performed when taking charge of waste or excess quantities and intended to verify its compliance with the specifications in force, in preparation for transferring responsibility" (RD of 30 March 1981, article 1)

2.2 Functioning rules

The functioning rules of ONDRAF/NIRAS are established by the provisions in the legal and regulatory framework.

- ONDRAF/NIRAS may carry out its missions using its own resources, sub-contract them, or allow them to be performed by third parties under its responsibility. The long-term management of radioactive waste does however fall under the exclusive competence of ONDRAF/NIRAS.

  Belgoprocess, the operational subsidiary of ONDRAF/NIRAS since 1986, is notably responsible for treating and conditioning radioactive waste from the majority of Belgian producers who do not perform these operations themselves, along with the storage of conditioned waste, pending a solution that can become definitive for long-term management. Belgoprocess operates centralised facilities located in Mol and Dessel, which belong to ONDRAF/NIRAS and are under its responsibility.

EURIDICE is the economic interest grouping created by ONDRAF/NIRAS and SCK•CEN in 1995, principally to manage the HADES underground research laboratory.

- ONDRAF/NIRAS is supervised by the Federal Government through the ministers responsible for Energy and the Economy. An agreement between ONDRAF/NIRAS and the safety authority — the Federal Agency for Nuclear Control or FANC — established in execution of article 33 of the general regulations to protect the population, workers and the environment against the hazards of ionising radiation [35], called the "general regulations on the protection against ionising radiation" in the rest of the text, aims to allow "*mutual consultation and exchange of information on the aspects of managing radioactive waste that may affect how the competences of the two institutions are exercised*" [translation ONDRAF/NIRAS].

  FANC, which is supervised by the minister for the Interior, is the agency responsible for promoting the protection of man and the environment against the hazards of ionising radiation. In particular, it is responsible for establishing regulations and standards for radiation protection in line with international recommendations and European directives, granting nuclear licences for construction and operation, as well as for decommissioning or closure, to nuclear facility operators (including disposal facility operators), granting nuclear licences to transporters of radioactive waste, controlling compliance with the provisions of the licences and inspecting nuclear facilities, providing radiological surveillance of the Belgian territory, contributing to the organisation of the national nuclear and radiological emergency plan, and ensuring the security of nuclear materials.

- ONDRAF/NIRAS must work at cost price and charge those using its services — radioactive waste producers — no more or less than the amounts necessary to ensure the safe management of their waste, in accordance with the "polluter pays" principle (see section 4.4 for a description of the organisation for the financing of radioactive waste management).

The organisation of radioactive waste management in Belgium is illustrated in Figure 5.

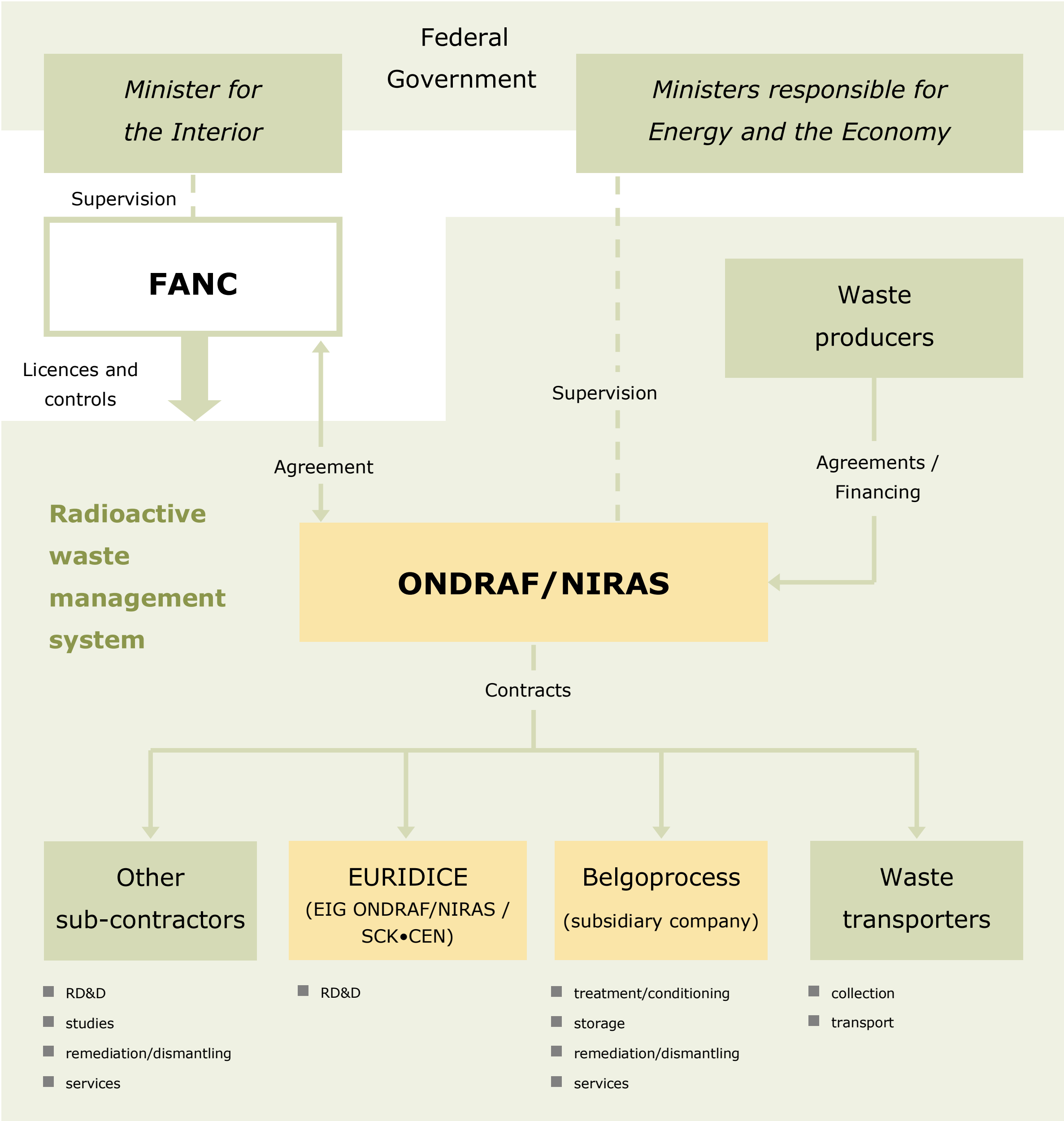


Figure 5 – Simplified representation of the organisation of radioactive waste management in Belgium.

3 Scope of the ONDRAF/NIRAS radioactive waste management system

The scope of the ONDRAF/NIRAS radioactive waste management system designates its area of application, which is defined by the legal and regulatory framework. The diverse range of possible cases, including the observation that some substances which do not currently satisfy the definition of radioactive waste could eventually enter the ONDRAF/NIRAS management system, justifies a review of these different cases (see chapter 4 for a description of the management system developed by ONDRAF/NIRAS). Various examples of radioactive waste are also given in section 4.3, which summarises the technical inventory of conditioned waste. Annex A1 gives an overview of the origins and characteristics of B&C waste [36].

3.1 Conditions under which a substance must be managed by ONDRAF/NIRAS

In accordance with its mission, ONDRAF/NIRAS must manage substances that satisfy the definition of radioactive waste, whatever their origin and provenance, which are present on Belgian territory and which ONDRAF/NIRAS has been requested to take charge of by their producer or owner [5], as well as radioactive waste of Belgian origin temporarily abroad, for example for treatment.

3.1.1 To be radioactive waste

Generally, radioactive waste is considered as a substance or object which has both the characteristic of being waste and that of being radioactive. The determination of what constitutes radioactive waste goes back to its producer or owner.

According to the Law of 15 April 1994 on the protection of the population and the environment against the hazards of ionising radiation and establishing FANC [37], a radioactive substance is a substance that contains *"one or several radionuclides, the activity or concentration of which cannot be ignored for radiation protection reasons"*

[5] Or by FANC in some cases.

Radioactive waste of foreign origin: "radioactive waste that has obtained its radioactivity characteristics outside Belgium, except if this radioactivity is a result of equipment and/or waste of Belgian origin treated abroad" (RD of 30 March 1981, article 1)

(article 1) [translation ONDRAF/NIRAS]. Most of the time, the radioactive or non-radioactive nature of a substance can be established based on criteria in the general regulations on the protection against ionising radiation. For cases that are currently not covered by these rules (section 3.2.2.4), the radioactive or non-radioactive nature is established by FANC on a case-by-case basis.

In accordance with the Royal Decree of 30 March 1981, determining the ONDRAF/NIRAS missions and establishing its functioning rules [2], as amended, radioactive waste is "*any material for which no use is foreseen and which contains radionuclides in concentrations in excess of those that the competent authorities consider permissible in materials suitable for use or discharge without control" (article 1)* [translation ONDRAF/NIRAS]. However, this definition poses difficulties pertaining to its application, in that the general regulations on the protection against ionising radiation do not yet include values for work activities and remediation operations (section 3.2.2.4).

In its raw state, radioactive waste may be in the form of a solid, liquid or gas. In some cases and under certain conditions, facilities with a nuclear licence from FANC may perform limited and controlled gas or liquid effluent discharges into the environment. The majority of radioactive waste [6] is however transformed into a solid form by treatment and conditioning, the conditioned waste packages then being stored pending an operational solution for their long-term management (section 4.2).

3.1.2 To be present on Belgian territory or be abroad while being of Belgian origin [7]

In principle, only radioactive waste located on Belgian territory should be taken charge of by ONDRAF/NIRAS. However, in some cases, Belgian radioactive waste or waste of Belgian origin, such as radioactive waste from the reprocessing of Belgian irradiated nuclear fuel, is located abroad and, being the responsibility of a Belgian owner, must eventually return to Belgium.

[6] With the exception of long-lived, predominantly very low-level and low-level, solid waste stored in bulk in interim storage facilities (UMTRAP and "Bankloop") by Umicore in Olen (sections 10.2.5 and 11.1.1.1).

[7] In the case of the reprocessing of irradiated Belgian fuel abroad, the constraints related to the reprocessing process are such that Belgium does not recover conditioned waste from the reprocessing of its own fuel, but rather conditioned reprocessing waste with radiological and physicochemical characteristics *equivalent* to those of the fuel sent for reprocessing. This equivalence is established based on an accounting management system for waste, called the Units of Residue system, established by COGEMA (which became AREVA NC). Synatom has submitted the allocation and attribution rules for the resulting residues to ONDRAF/NIRAS, which has approved them.

3.1.3 To have been subject (or likely to be subject) to a request to take charge of it

Source: "radioactive substance, or device or facility able to emit ionising radiation or containing radioactive substances" (RD of 20 July 2001, article 2)

The vast majority of radioactive waste producers and owners request that ONDRAF/NIRAS takes charge of the management of their radioactive waste. However, they are not required to do so and can temporarily store their waste, provided that they comply with the conditions of the storage licence which they would have had to request from FANC. This is how, for example, hospitals and research laboratories store radioactive waste of half-life that is sufficiently short for the level of radioactivity to decrease very quickly and for the waste to be quickly considered as non-radioactive. ONDRAF/NIRAS alone is entitled to provide the long-term management of radioactive waste and operate disposal facilities.

3.2 Scope of the management system

Although it is relatively easy to define the theoretical scope of the management system for radioactive waste based on the provisions of the legal and regulatory framework, there is a certain vagueness with regard to the status of "waste" or the radioactive nature (as stated in the Law of 15 April 1994) of certain substances. Therefore, ONDRAF/NIRAS cannot fully anticipate which of these substances will eventually acquire the status of radioactive waste. In other words, the actual scope of its management system is currently more restricted than its theoretical scope.

The analysis which follows distinguishes between three types of substance: those which are in the ONDRAF/NIRAS management system or which it knows will be in it because they will be declared as waste and will be a subject to a request for ONDRAF/NIRAS to take charge of them (section 3.2.1), those which are likely to eventually enter its management system, but where the status of "radioactive waste" is not currently established (section 3.2.2), and those which are excluded by definition (section 3.2.3). This is summarised in Table 1 (section 3.2.4).

In the text, an illustration of the types of conditioned category B and C waste is indicated (see annex A1) in which the (types of) substances mentioned in the analysis that follows can be found. The types of category A waste in which these substances can also be found *are not specified because they are not the subject of the Waste Plan.* That said, in 2009, they represented more than 80% of the estimated volume (section 4.3.1) of all waste of categories A, B and C to be managed in the long term (section 4.2.3).

3.2.1 Substances that are or will be in the management system

In order to prepare and plan for the various components of its radioactive waste management mission, ONDRAF/NIRAS takes into consideration not only existing radioactive waste, but also the forecasts for future waste production, including Belgian radioactive waste and waste of Belgian origin currently abroad and which must eventually return to Belgium. To do so, it uses the information that radioactive waste producers are required to provide as part of the periodic update of its technical radioactive waste inventory (section 4.3) and as part of the contracts that they sign with ONDRAF/NIRAS for the collection of their waste.

Orphan source: "source where the level of activity when it is discovered is higher than the exemption level given in appendix IA and which is not under regulatory control, either because it has never been subject to such control or because it has been abandoned, lost, stolen or transferred to a new holder without notification in due form to the competent authority or without the recipient having been informed of it" (RD of 20 July 2001, article 2)

Practice: "human activity likely to increase exposure of individuals to ionising radiation from an artificial or natural radiation source when natural radionuclides are processed for their radioactive, fissile or fertile properties, except in the event of emergency exposure" (RD of 20 July 2001, article 2)

With the exception of orphan* sources* (section 3.2.1.4) and military waste [8] that ONDRAF/NIRAS is called upon to take charge of, the substances that are or will eventually be in its management system come from *practices** authorised by FANC or remediation operations on grounds with radioactive pollution decided by FANC. The values that are used to distinguish between substances considered as radioactive and others are in fact those set by the general regulations on the protection against ionising radiation (called clearance* and exemption* levels for solid waste and discharge limits for liquid and gas effluents) [35], which are only applicable to waste from authorised practices. These practices are activities that involve radioactive substances due precisely to their radioactive nature, in contrast to *work activities** (section 3.2.2.4).

The substances that are or will eventually be in the ONDRAF/NIRAS radioactive waste management system can be divided into six groups:

- radioactive waste from authorised practices present on Belgian territory (excluding waste contained in Umicore's licensed storage facilities);
- radioactive waste from reprocessing that is still to return from abroad;
- Belgian radioactive waste, other than reprocessing waste, that is temporarily abroad;
- orphan sources;
- radioactive waste contained in Umicore's two licensed interim storage facilities in Olen (UMTRAP and "Bankloop");
- radioactive waste from remediation operations already decided by FANC.

3.2.1.1 Radioactive waste from authorised practices on Belgian territory (excluding waste contained in Umicore's licensed storage facilities)

Authorised practices range from activities related to the nuclear fuel cycle (fabrication of fuel and production of electricity by the nuclear power plants in Doel and Tihange — see Inset 3 in section 3.2.1.2) to radioactive waste management itself (treatment, conditioning and storage), research activities, radionuclide production for medical and industrial use, the use of these radionuclides for medical diagnosis (for example metastable technetium-99 used in imaging) or therapeutic purposes (for example cobalt-60 used in radiotherapy) or even the use by industry of measuring devices containing radioactive sources (Figure 6) (see Table 2 in section 4.3 for a list of the main licensed nuclear facilities operators).

[8] The Ministry of Defence has its own licensing system. ONDRAF/NIRAS takes charge of small quantities of conditioned military waste. These are mainly pieces from old aircraft and tank cockpits, such as old dials and other objects that were once coated with paints containing radium to make them luminescent (line d-4 in annex A1). (Belgium does not possess nuclear weapons.)

Figure 6 – From left to right and from top to bottom: glove boxes (now being dismantled) used in the past by Belgonucleaire for the fabrication of nuclear fuel (source: Belgonucleaire); inside of SCK•CEN's BR2 research reactor core (source: SCK•CEN); radioelement production laboratory (source: IRE); use of a radioactive source in radiotherapy (source: Nagra); control of welds on a pipe using a radioactive source (source: Nagra).

Radioactive waste from authorised practices is current production waste, including reprocessing waste from irradiated nuclear fuel (Figure 7), and waste from the dismantling of nuclear facilities. It is highly diverse in nature and includes, for example, pieces of out-of-service equipment, dissolution effluents from irradiated fuel management, protective clothing, residues from waste water treatment in nuclear power plants, filters, sealed sources, solid waste and liquid effluents from laboratories, along with, to a large extent, concrete and metals from dismantling operations. Treated and conditioned waste that is not classified as category A is classified as category B or C.

Clearance: means the removal of radioactive materials or objects associated with authorised practices from any subsequent regulatory control by the safety authority

Exemption: means the determination by the safety authority that a source or practice does not have to be subject to some or all aspects of regulatory control because exposure (including potential exposure) arising from the source or practice is too low to justify the application of these aspects

Work activity: "an activity that is not a practice, but which implies the presence of natural ionising radiation sources and which is likely to lead to a notable increase in human exposure, not negligible from the point of view of protection against ionising radiation" (RD of 20 July 2001, in accordance with article 1)

Figure 7 – Nuclear fuel assembly and metallic waste recovered during fuel reprocessing (source: AREVA NC).

Two particular types of current production waste are irradiated nuclear fuel declared as waste by its owner and excess quantities of enriched fissile materials and plutonium-bearing materials declared as waste. To date, ONDRAF/NIRAS has not been requested to take charge of irradiated fuel from Belgian commercial nuclear reactors or enriched fissile materials and plutonium-bearing materials declared as waste. In fact, the status (resource or waste) of such fuel (section 3.2.2.1) and materials (section 3.2.2.3) is not specified by their owners, creating an uncertainty for ONDRAF/NIRAS that is particularly significant with regard to irradiated commercial fuel (section 10.2.1). However, ONDRAF/NIRAS has received a request to take charge of irradiated fuel from *Ghent University's* Thétis research reactor (line c1-2 in annex A1), the dismantling of which started in early 2010 (Figure 8). (Also, at the request of SCK•CEN, ONDRAF/NIRAS provides storage for irradiated fuel from SCK•CEN's BR3 research reactor (line c1-1 in annex A1) (Figure 8).)

Figure 8 – Unloading of irradiated fuel from *Ghent University's* Thétis research reactor at Belgoprocess (source: Belgoprocess) and storage of irradiated fuel from SCK•CEN's BR3 research reactor in Castor containers on the BP1 site of ONDRAF/NIRAS operated by Belgoprocess (source: Belgoprocess / ONDRAF/NIRAS).

There have never been any uranium enrichment activities in Belgium, there are no longer any extraction activities [9], and since the closure in 1975 of the Eurochemic pilot reprocessing plant built as part of an experimental project by the Organisation for Economic Cooperation and Development (OECD), there are no longer any reprocessing activities. The site, facilities and residues from the reprocessing activities of Eurochemic (mainly lines c3-1 to c3-9, c4-10 and c4-11 in annex A1) were transferred to the Belgian State in late 1981, under the terms of an agreement between Eurochemic and the Belgian Government. Eurochemic continued to manage the site on behalf of the Government until the end of 1984, after which time its management was transferred to the company Belgoprocess that had just been created with a view to the possibility of bringing the Eurochemic facilities back into service. With this project definitively abandoned, in late 1986, the Belgian State made ONDRAF/NIRAS responsible for all of Belgoprocess' shares, along with the management of the facilities and the waste arising from the Eurochemic operation and the dismantling of its disused facilities.

3.2.1.2 Radioactive reprocessing waste that is still to return from abroad

With the exception of the first two foreign reprocessing contracts for fuel from Belgian nuclear power plants (40 tHM, both signed in 1976), reprocessing contracts provide for the return of radioactive reprocessing waste to Belgium (Inset 3, Figure 9). These other contracts are the two reprocessing contracts for fuel from nuclear power plants (630 tHM) signed in 1978 by Synatom and COGEMA (which became AREVA NC in 2006), located in The Hague in France (see also section 3.2.2.1), along with the reprocessing contracts for irradiated fuel from SCK•CEN's BR2 research reactor. These latter contracts were signed in the late 1990s with COGEMA and UKAEA Ltd, Dounreay site (United Kingdom), which became DSRL (Dounreay Site Restoration Limited) in 2008.

In addition, article 8 of the French programme Law of 28 June 2006 relating to the sustainable management of materials and radioactive waste [38] stipulates that France cannot provide the long-term management of radioactive waste of foreign origin and that radioactive reprocessing waste must be returned to the countries of origin of the fuels that have been reprocessed.

ONDRAF/NIRAS takes care of the reprocessing waste on its return to Belgium (lines b2-1 to b2-5 and c2-1 to c2-3 in annex A1).

[9] This was uranium extraction in the phosphate industry and radium and uranium extraction from uranium ore in Olen.

Inset 3 – Cycle for UO_2 nuclear fuel: from uranium mining to the long-term management of radioactive waste

Uranium, the most common nuclear fuel, is a relatively abundant mineral in the earth's crust. Like other minerals, it must be *mined* in order to be used.

Natural uranium appears in the form of a mix of mainly uranium-235 and uranium-238. Uranium-235 represents only 0.7% of the mix and is fissile. Since the majority of nuclear reactors require a fuel with a higher content of fissile uranium, natural uranium must be *enriched* into uranium-235, an operation that also produces depleted uranium.

During the *fabrication* of nuclear fuel, uranium oxide is compressed into pellets, which are piled into watertight hulls to form fuel rods, which are then brought together in a fuel assembly.

The fuel assemblies are then loaded into the reactor, where the fuel is *used*. The various reactions that take place in the reactor core transform the fuel, which degrades over time. After about four years, the fuel must be taken out of the reactor, although it still contains significant amounts of fissile materials.

On its removal from the reactor, the irradiated fuel can either be considered as radioactive waste, in which case the fuel cycle is referred to as *open*, or as a recoverable material, in which case the fuel cycle is said to be *closed*. In the case of a closed fuel cycle, the fuel is *reprocessed* in order to recover the unused uranium and the plutonium generated. The uranium and plutonium, which represent approximately 95% of the initial uranium mass, can then be recycled in the fabrication of fresh fuel, with the remaining 5% being transformed into radioactive waste.

Radioactive waste from the fuel cycle, whether open or closed, must be *managed*, including in the long term, in such a way as to protect man and the environment from the risks that it presents.

The *only fuel cycle operations in Belgium* are the fabrication of fresh fuel, its use in nuclear power plants, and the management of the resulting radioactive waste. There have never been any enrichment activities. There are no longer any extraction or reprocessing activities.

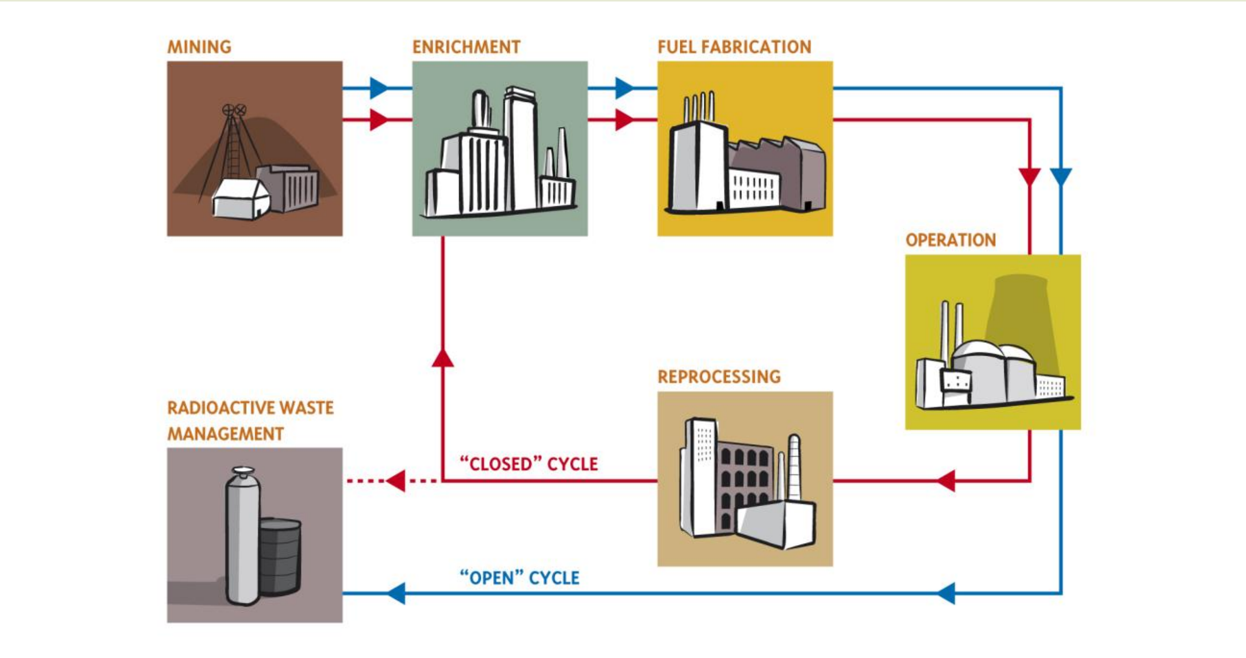


Figure 9 – Filling of a container of vitrified waste from reprocessing (source: AREVA NC) and transfer of a shielded transport container containing 28 containers of vitrified waste (source: Belgoprocess).

3.2.1.3 Belgian radioactive waste, other than reprocessing waste, that is temporarily abroad

Belgian radioactive waste other than reprocessing waste that may be abroad must also eventually return to Belgium. ONDRAF/NIRAS takes charge of this waste on its return to Belgium. This waste is mainly filters that concentrate the contamination (in the case of the treatment of parts or equipment by decontamination) and metallic slag (in the case of metal recycling in nuclear foundries, mainly by Studsvik, in Sweden). This waste is exclusively category A.

3.2.1.4 Orphan sources

In addition to the sources used within the scope of authorised practices (section 3.2.1.1), there are sources that are not under regulatory control, for example because they pre-date the licensing system, are not subject to it, or have been lost or abandoned. These sources, which are likely to be mixed with conventional waste, may be detected by radiation detection equipment installed at the entrance to landfill sites or conventional waste treatment facilities. These include ionising smoke detectors, radioactive lightning conductors (the installation of which has been banned since 1985 and which have been completely banned since 2006 — Figure 10), objects covered in luminescent paint containing radium, short-lived medical waste and, sometimes, sealed sources used for medical purposes or from measurement and control devices used in industry. If their owner cannot be identified and FANC declares them as waste to ONDRAF/NIRAS, ONDRAF/NIRAS takes charge of them (line d-2 in annex A1; for the financing for the management of orphan sources, see section 4.4).

Figure 10 – Radioactive lightning conductor and smoke detectors.

3.2.1.5 Particular case of Umicore's two licensed interim storage facilities in Olen (UMTRAP and "Bankloop")

Umicore (formerly Union Minière) has two storage facilities in Olen — the UMTRAP and "Bankloop" facilities — licensed for interim storage. The substances that they contain, long-lived, mostly very low-level and low-level, non-conditioned wastes, thus have radioactive waste status by definition and will need to be provided with long-term management by ONDRAF/NIRAS.

Various questions are currently being asked with regard to the management of the UMTRAP and "Bankloop" facilities (section 11.1.1.1). Furthermore, the UMTRAP facility raises an additional question, in that it is possible that some of its contents may have to be managed off site and will therefore have to be extracted, if necessary for inclusion in a future facility for the long-term management of B&C waste (section 10.2.5). However, none of these issues calls into question the need for a decision in principle for the long-term management of B&C waste and the management solution recommended by ONDRAF/NIRAS (chapter 8).

3.2.1.6 Radioactive waste from remediation operations already decided by FANC

In 2000, Umicore's D1 landfill site in Olen, which contains radium-bearing and chemical waste, was the subject of a remediation decision by the Protection Service against Ionising Radiation (*Service de Protection contre les radiations ionisantes* or SPRI), the safety authority at the time [39]. The radiological remediation methods for this landfill site are still to be established (section 11.1). The long-term management of the radioactive substances resulting from this remediation operation will have to be provided by ONDRAF/NIRAS.

3.2.2 Substances likely to enter the management system eventually

Certain groups of substances, for which it is not yet established whether they satisfy the definition of a radioactive substance or where the status of waste is currently not established and which cannot therefore enter the ONDRAF/NIRAS management system, have nevertheless been identified as being likely to satisfy the definition of radioactive waste in the future, following decisions external to ONDRAF/NIRAS. They would then enter the ONDRAF/NIRAS management system. These various groups of substances are as follows:

- non-reprocessed irradiated fuel from nuclear power plants;
- uranium and plutonium from reprocessing;
- enriched fissile materials and plutonium-bearing materials;
- remediation waste.

3.2.2.1 Non-reprocessed irradiated fuel from nuclear power plants

In accordance with the resolution of 22 December 1993 by the Chamber [40] confirmed by the Council of Ministers the same year and reconfirmed by the Council on 4 December 1998 [41], in 1993, Belgium suspended the reprocessing (see Inset 3 in section 3.2.1.2) of irradiated fuel from nuclear power plants, also called irradiated commercial fuel.

> *"The Chamber […] orders that the Government: 1) in the future, no longer prioritises the reprocessing strategy compared with the conditioning and direct disposal strategy […]. The Government […] must create the conditions to allow the conditioning and direct disposal strategy to be developed as an alternative; 2) over a period of 5 years: does not execute the reprocessing contract signed in 1990; does not lift the options provided for in this contract that Belgium had to lift in 1995; does not negotiate any new contract during this period dedicated to the review of alternatives;"* [translation ONDRAF/NIRAS]

According to the report from the Council of Ministers session of 4 December 1998, *"The Government also asks Synatom not to sign any reprocessing contract without its formal agreement"* [translation ONDRAF/NIRAS].

Since the reprocessing suspension came into force, Electrabel has been storing irradiated fuel at the power plant sites (Figure 11). Their owner, Synatom, which is responsible for the management of both fresh and irradiated fuel, does not declare its irradiated fuel as excess material and does not ask ONDRAF/NIRAS to take charge of it as waste.

ONDRAF/NIRAS is faced with uncertainty in terms of whether or not it will have to manage irradiated fuel from nuclear power plants and, if so, from when. This uncertainty is central to one of the key related issues (section 10.2.1). The resolution by the Chamber of 22 December 1993 however requires ONDRAF/NIRAS to give equal consideration to the study of the long-term management of reprocessing waste and that of non-reprocessed irradiated fuel (section 4.2.3). ONDRAF/NIRAS therefore includes non-reprocessed irradiated fuel in its technical waste inventory (section 4.3) as category C waste (lines b2-6 and b2-7 in annex A1).

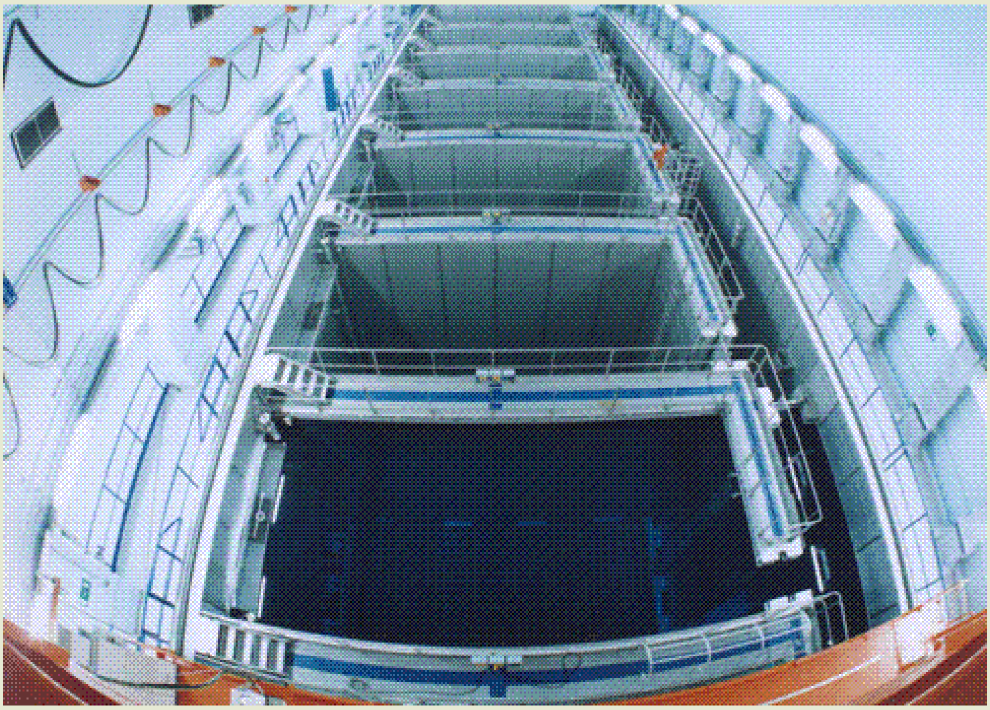


Figure 11 – Storage pools for Synatom's irradiated fuel at the Tihange nuclear power plant (source: Electrabel).

3.2.2.2 Uranium and plutonium from reprocessing

Uranium and plutonium from the reprocessing of Belgian irradiated fuel may theoretically enter the ONDRAF/NIRAS management system. However, in practice they do not currently do so. In fact,

- the uranium and plutonium recovered during the reprocessing of Synatom's commercial fuel have been put to good use, notably through the fabrication of fresh fuel for Belgian nuclear power plants;
- in accordance with contractual provisions, the uranium and plutonium recovered during the foreign reprocessing of irradiated fuel from SCK•CEN's research reactors are not being returned to Belgium.

3.2.2.3 Enriched fissile materials and plutonium-bearing materials

Within the framework of its mission known as the "nuclear liabilities inventory", ONDRAF/NIRAS asks nuclear operators about the quantities of radioactive materials that they hold. According to this inventory [42], several operators hold enriched fissile materials and/or plutonium-bearing materials (materials excluding fuel, as stated in the Royal Decree of 30 March 1981) that they do not declare as excess quantities and therefore do not ask (and have never asked) ONDRAF/NIRAS to take charge of as waste. This situation means that ONDRAF/NIRAS is faced with the issue of not knowing whether it will one day have to manage such materials and, if so, from what date (section 10.2.4).

3.2.2.4 Remediation waste

In addition to cases related to radiological emergency situations in the event of an accident taking place within or outside Belgium, certain types of situations are likely to present a risk of long-term radiation exposure to man and the environment and therefore require protective measures, even if they do not usually represent an immediate danger to the public and the environment. Although this eventuality appears in the general regulations on the protection against ionising radiation, in accordance with European Directive 96/29/Euratom on the same subject [43], this rule does not define the procedure and criteria necessary to assess these situations and to define the protective measures required, called *interventions**.

Intervention: "human activity intended to prevent or reduce human exposure to ionising radiation from sources that are not part of a practice or are not under control, by acting on the ionising radiation sources, the exposure pathways and the people themselves" (RD of 20 July 2001, article 2)

There are three types of situations likely to present a risk of long-term radiation exposure for man and the environment and therefore to require an intervention.

- *Industrial activities using raw materials containing naturally occurring radioactive substances, without the radioactive nature being a sought-after property of these substances.* These industrial activities, which until now have not required a nuclear licence from FANC, are designated in the general regulations on the protection against ionising radiation under the name of *work activities* (for example activities in the phosphate industry and activities in the cement industry — section 11.2). The raw materials and residues from the processes that contain non-negligible concentrations of natural radionuclides and may therefore lead to a risk of exposure to ionising radiation are designated by the acronyms NORM (*naturally occurring radioactive materials*) and TENORM (*technologically enhanced, naturally occurring radioactive materials*).

  Also, the "waste" status of residues from processes used in work activities is not always clear. Residues from some of these activities are indeed used as raw materials for other work activities. In addition, new recycling channels are currently being considered. This may help to reduce the volumes of residues that ultimately are to be considered as radioactive waste.

- *Grounds that present radioactive pollution following past activities* (sections 11.1.1 and 11.3).

- *Grounds that have become contaminated following an accident taking place within or outside Belgium.*

FANC is currently developing the regulatory framework relating to interventions, in consultation with ONDRAF/NIRAS and the Regions, the Regions acting as competent authorities in terms of the environment (section 11.4).

If necessary, two types of intervention can be decided by FANC to protect against the risks of long-term radiation exposure.

- The implementation of a *risk management plan*, i.e. a collection of administrative measures, potentially complemented with control measures, to intervene at possible *exposure pathways*. A risk management plan can, for example, require polluted grounds to be assigned for specific uses or be fenced in order to avoid unauthorised access. Such a plan does not lead to the production of radioactive waste and therefore does not impact the ONDRAF/NIRAS management activities.

Radioactive waste of foreign origin: "radioactive waste that has obtained its radioactivity characteristics outside Belgium, except if this radioactivity is a result of equipment and/or waste of Belgian origin treated abroad" (RD of 30 March 1981, article 1)

- A radiological *remediation*, i.e. a collection of actions and measures intended to intervene at the *source of the exposure.* Remediation can in particular involve the improved isolation of the source of the exposure from man and the environment, for example by establishing artificial barriers (such as protective layer systems), or its full or partial removal. By definition, remediation generates radioactive waste, which requires specific long-term management on site or in a centralised long-term management facility.

As long as the regulations relating to interventions are not complete, FANC does not have the necessary elements to be able to give a systematic and consistent judgement on all the cases that could require intervention measures. ONDRAF/NIRAS is therefore not currently able to forecast the "generation" of radioactive waste associated with remediation operations.

3.2.3 Substances excluded from the management system

Radioactive waste of foreign origin* is explicitly excluded from the ONDRAF/NIRAS management system, unless there is an agreement from the supervisory authority. To date, there is only one agreement of this type. It authorises ONDRAF/NIRAS to take charge of the very low quantities of radioactive waste from the Grand Duchy of Luxembourg (maximum 0.1 m^3 in conditioned form per year; line d-2 in annex A1), thus without returning them to the country of origin [44]. The signing of commercial agreements for the treatment and conditioning of radioactive waste of foreign origin in Belgium must receive the approval of the supervisory authority of ONDRAF/NIRAS. These agreements must provide for the return of conditioned waste to the country of origin [10].

By-products of nuclear fuel cycle operations before the fuel is used in a reactor are also excluded from the ONDRAF/NIRAS management system if these operations are carried out abroad, which complies with usual practice in terms of economic commercial activities.

- Residues from uranium mining (tailings) remain the property of companies active in uranium mining.
- Depleted uranium and other residues resulting from natural uranium enrichment remain the property of companies that practice enrichment. There are no companies of this type in Belgium.
- Residues from foreign fabrication of nuclear fuel used in Belgium remain the property of the fuel manufacturer.

[10] In the past there have been a few exchanges, approved by the competent authorities, of small amounts of foreign waste processed and conditioned in Belgium against Belgian waste with equivalent radiological characteristics.

3.2.4 Summary

The theoretical and actual scope of the ONDRAF/NIRAS radioactive waste management system are shown in Table 1. This table is a generic review of practices and activities likely to be the source of radioactive waste production from current production or dismantling and examines on a case-by-case basis whether the "by-products" of these practices and activities satisfy the definition of radioactive waste subject to or likely to be subject to a request for ONDRAF/NIRAS to take charge of it. The designation "by-products", although very vague, is used because it does not prejudge the "waste" nature or the radioactive nature of the materials and equipment identified as being likely to satisfy the definition of radioactive waste.

The theoretical scope of the ONDRAF/NIRAS radioactive waste management system, defined by the legal and regulatory framework, corresponds to the green and grey rows in the table:

- the green rows relate to types of radioactive waste that are or will be in the ONDRAF/NIRAS management system;
- the grey rows correspond to types of substances that are not in the ONDRAF/NIRAS management system because they do not currently satisfy the definition of radioactive waste, but are within its theoretical scope and are therefore likely to enter the management system in the future, following decisions that are external to ONDRAF/NIRAS.

The orange rows relate to substances that are not to be managed by ONDRAF/NIRAS. They are thus not mentioned anymore in the rest of the text.

Table 1 – Simplified overview of the scope of the ONDRAF/NIRAS radioactive waste management system. In green, the substances that are or will eventually be in the system; in light grey, the substances that are within the theoretical scope of the management system, but which are not (yet) part of it in practice; in orange, the substances that are excluded. [✓: yes; ×: no]

origin	"by-product"	radioactive?	waste?	on Belgian territory?	subject (or likely to be subject) to a request to take charge of it?	⇒	to be managed by ONDRAF/NIRAS?	sections and parts
COMMERCIAL NUCLEAR FUEL CYCLE								
Mining	Residues (tailings)	✓	✓	×	×	⇒	×	3.2.3
Enrichment	Depleted uranium	✓	decision by owner	×	×	⇒	×	3.2.3
Fuel fabrication	Materials/equipment	✓	×	not relevant	not relevant	⇒	×	–
in Belgium	Materials/equipment	✓	✓	✓	✓	⇒	✓	3.2.1.1, 2nd part
abroad	Materials/equipment	✓	✓	×	×	⇒	×	3.2.3
Operation of commercial power plants	Materials/equipment	✓	×	not relevant	not relevant	⇒	×	–
	Materials/equipment	✓	✓	✓	✓	⇒	✓	3.2.1.1, 2nd part
	Non-reprocessed irradiated fuel	✓	decision by owner	✓	decision by owner	⇒	?	3.2.2.1, 2nd part, 10.2.1
Foreign reprocessing of commercial fuel	Uranium and plutonium	✓	decision by owner	have been recycled	if resumption of reprocessing, decision by owner	⇒	?	3.2.2.2, 10.2.1
	Residues from reprocessing	✓	✓	return is contractual	✓	⇒	✓	3.2.1.2, 2nd part
Dismantling of commercial power plants	Materials/equipment	✓	×	not relevant	not relevant	⇒	×	–
	Materials/equipment	✓	✓	✓	✓	⇒	✓	3.2.1.1, 2nd part
RESEARCH AND NUCLEAR PILOTS, TREATMENT, CONDITIONING, STORAGE, RADIONUCLIDE PRODUCTION FOR MEDICAL AND INDUSTRIAL USE, USE OF SOURCES IN MEDICAL AND INDUSTRIAL ENVIRONMENTS, ETC.								
Use of research reactors	Non-reprocessed irradiated fuel	✓	decision by owner	✓	decision by owner	⇒	✓ (one case)	3.2.1.1, 2nd part
Foreign reprocessing of Belgian research fuel	Uranium and plutonium	✓	decision by owner	not returned (contractual)	decision by owner	⇒	?	3.2.2.2
	Residues from reprocessing	✓	✓	return is contractual	✓	⇒	✓	3.2.1.2, 2nd part
Reprocessing in Belgium (Eurochemic)	Uranium and plutonium	✓	returned to the owner	×	×		×	3.2.1.1
	Residues from reprocessing	✓	✓	✓	✓	⇒	✓	3.2.1.1, 2nd part
Other research activities and various operating and dismantling activities	Materials/equipment	✓	×	not relevant	not relevant	⇒	×	–
	Materials/equipment	✓	✓	✓	✓	⇒	✓	3.2.1.1, 2nd part
	Excess enriched fissile materials and plutonium-bearing materials	✓	decision by owner	✓	decision by owner	⇒	?	3.2.2.3, 2nd part, 10.2.4
	Orphan sources	✓	✓	✓	✓	⇒	✓	3.2.1.4, 2nd part
Storage by Umicore of radium-bearing waste in licensed facilities	Residues from past activities	✓	✓	✓	decision by Umicore or FANC	⇒	✓ (eventually)	3.2.1.5, 10.2.5, 11.1.1.1
Remediation of a landfill site containing radium-bearing waste from Umicore	Residues from past activities	✓	✓	✓	decision by Umicore or FANC	⇒	✓ (eventually)	3.2.1.6, 10.2.5, 11.1.1.2
FOREIGN SUBSTANCES								
of Belgian origin (excluding reprocessing)	Residues from treatment	✓	✓	return is contractual	✓	⇒	✓	3.2.1.3, 2nd part
of foreign origin	Materials/equipment	✓	✓	×	agreement from the supervisory authority on a case-by-case basis	⇒	if agreement from the supervisory authority	3.2.3
POSSIBLE FUTURE REMEDIATION OPERATIONS								
… of sites presenting old radioactive pollution	Residues from past activities	decision by FANC	✓	✓	decision by owner or FANC	⇒	long-term management system(s) to be developed to take charge of the materials that will have been defined as radioactive waste by FANC	3.2.2.4, 11.1.1, 11.3
… of sites of work activities	NORM and TENORM residues	decision by FANC	decision by owner or FANC	✓	decision by owner or designated debtor or FANC	⇒		3.2.2.4, 11.2
… in case of radioactive pollution following an accident	Contamination	decision by FANC	✓	✓	decision by owner or FANC	⇒		3.2.2.4

4 Radioactive waste management and its financing

The radioactive waste management system developed by ONDRAF/NIRAS (section 4.2) fits within a legal and regulatory framework, the key elements of which are given below (section 4.1). For all aspects of its implementation, this system relies on knowing as accurately as possible the quantities and types of waste that ONDRAF/NIRAS is managing and will be expected to manage (section 4.3). It is financed by radioactive waste producers in accordance with the "polluter pays" principle (section 4.4). This system has been described by ONDRAF/NIRAS in a detailed report [45].

4.1 Legal and regulatory framework

ONDRAF/NIRAS executes its mission, summarised in its mission statement as follows:

> *"On behalf of society, to manage all radioactive waste, now and in the future, through the development and implementation of solutions that respect society and the environment."* [translation ONDRAF/NIRAS]

by complying with various requirements and principles:

- requirements of the international conventions and treaties to which Belgium is a signatory and requirements of European directives (section 4.1.1);
- requirements of the Belgian legal and regulatory framework (section 4.1.2);
- principles and standards recommended at international level (section 4.1.3).

4.1.1 International conventions and treaties and European directives

The main international conventions and treaties to which Belgium is a signatory and that are relevant to radioactive waste management are as follows:

- Treaty establishing the European Atomic Energy Community (called the Euratom Treaty, 1957);
- Treaty on the Non-proliferation of Nuclear Weapons (called the Non-Proliferation Treaty or TNP, 1968);

- Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (called the London Convention, 1972) and its related protocol (1996);
- Convention on Environmental Impact Assessment in a Transboundary Context (called the Espoo Convention, 1991);
- Convention for the Protection of the Marine Environment of the North-East Atlantic (called the OSPAR Convention, 1992);
- Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (called the Joint Convention, 1997) [8];
- Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (called the Aarhus Convention, 1998).

The main relevant European directives in terms of radioactive waste management are as follows:

- Council Directive 85/337/EEC of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment [46];
- Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation [43];
- Council Directive 97/11/EEC of 3 March 1997 amending Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment [47];
- Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption [48];
- Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment [9];
- Directive 2003/4/EC of the European Parliament and of the Council of 28 January 2003 on public access to environmental information and repealing Council Directive 90/313/EEC [49];
- Directive 2003/35/EC of the European Parliament and of the Council of 26 May 2003 providing for public participation in respect of the drawing up of certain plans and programmes relating to the environment [13].

4.1.2 Belgian legal and regulatory framework

The main relevant texts from the Belgian legal and regulatory framework concerning radioactive waste management, besides those of the legal framework defining the ONDRAF/NIRAS missions and establishing its functioning rules (section 2.1), are as follows:

- for nuclear aspects (federal level):
  - Law of 15 April 1994 on the protection of the population and the environment against the hazards of ionising radiation and establishing FANC [37];
  - Royal Decree of 20 July 2001 relating to the general regulations of protection against ionising radiation [35];

- Law of 2 August 2002 containing assent to the Joint Convention [7]. This law enforces Belgium's commitment to respect the internationally accepted criteria and standards of the International Atomic Energy Agency (IAEA) in terms of radioactive waste and irradiated fuel management;

- for some environmental and public participation aspects (residual competences at federal level):
  - Law of 17 December 2002 containing assent to the Aarhus Convention [50];
  - Law of 13 February 2006 relating to the environmental assessment of the impacts of certain plans and programmes and the involvement of the public in drafting these plans and programmes for the environment [12], transposing Directives 2001/42/EC and 2003/35/EC;
  - Law of 5 August 2006 on public access to environmental information [51] transposing Directive 2003/4/EC;

- for the other environmental and public participation aspects (regional level):
  - the various elements of the regulatory framework of the Regions.

4.1.3 Internationally recommended principles and standards

The internationally recommended principles related to radioactive waste management are essentially the IAEA's nine principles of radioactive waste management [52], the IAEA's ten fundamental safety principles [53], and the three basic principles of radiation protection of the International Commission on Radiological Protection (ICRP) [26] (Inset 4, Inset 5 and Inset 6). These principles partially overlap. They are developed in a hierarchical system of international standards and recommendations by the IAEA (safety fundamentals, safety requirements, safety guides, etc.) (notably [54, 55]) and in a collection of recommendations by the ICRP (notably [26, 56, 57, 58]). The commonly accepted and applied strategy for radioactive waste management is that of concentration and confinement of waste, with isolation from the biosphere, as opposed to a strategy of dilution and dispersion of the radioactivity into the environment [52, 55].

Various other principles are relevant in addition to those directly related to radioactive waste management:

- the ethical principle of equity within a single generation (intragenerational equity), which is found in the seventh IAEA fundamental safety principle;

- the ethical principle of equity between generations (intergenerational equity), which is found in the IAEA radioactive waste management principles 4 and 5, in the seventh IAEA fundamental safety principle and in article 1, ii) of the Joint Convention [8]: *"to ensure that during all stages of spent fuel and radioactive waste management there are effective defenses against potential hazards so that individuals, society and the environment are protected from harmful effects of ionizing radiation, now and in the future, in such a way that the needs and aspirations of the present generation are met without compromising the ability of future generations to meet their needs and aspirations"*;

- the precautionary principle (Inset 1 in section 1.2);

- financial management principles, mainly the "polluter pays" principle.

Inset 4 – IAEA principles of radioactive waste management [52]

The nine principles of radioactive waste management are the basis for the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [8], ratified by Belgium in 2002 [7].

1. *Protection of human health.* Radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health.
2. *Protection of the environment.* Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment.
3. *Protection beyond national borders.* Radioactive waste shall be managed in such a way as to assure that possible effects on human health and the environment beyond national borders will be taken into account.
4. *Protection of future generations.* Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.
5. *Burdens on future generations.* Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations.
6. *National legal framework.* Radioactive waste shall be managed within an appropriate national legal framework including clear allocation of responsibilities and provision for independent regulatory functions.
7. *Control of radioactive waste generation.* Generation of radioactive waste shall be kept to the minimum practicable.
8. *Radioactive waste generation and management interdependencies.* Interdependencies among all steps in radioactive waste generation and management shall be appropriately taken into account.
9. *Safety of facilities.* The safety of facilities for radioactive waste management shall be appropriately assured during their lifetime.

Inset 5 – IAEA fundamental safety principles [53]

The ten fundamental safety principles are applicable to all circumstances and actions involving a radiological risk and therefore encompass the field of radioactive waste management.

1. *Responsibility for safety.* The prime responsibility for safety must rest with the person or organization responsible for facilities and activities that give rise to radiation risks.
2. *Role of government.* An effective legal and governmental framework for safety, including an independent regulatory body, must be established and sustained.
3. *Leadership and management for safety.* Effective leadership and management for safety must be established and sustained in organizations concerned with, and facilities and activities that give rise to, radiation risks.
4. *Justification of facilities and activities.* Facilities and activities that give rise to radiation risks must yield an overall benefit.
5. *Optimization of protection.* Protection must be optimized to provide the highest level of safety that can reasonably be achieved.
6. *Limitation of risks to individuals.* Measures for controlling radiation risks must ensure that no individual bears an unacceptable risk of harm.
7. *Protection of present and future generations.* People and the environment, present and future, must be protected against radiation risks.
8. *Prevention of accidents.* All practical efforts must be made to prevent and mitigate nuclear or radiation accidents.
9. *Emergency preparedness and response.* Arrangements must be made for emergency preparedness and response for nuclear or radiation incidents.
10. *Protective actions to reduce existing or unregulated radiation risks.* Protective actions to reduce existing or unregulated radiation risks must be justified and optimized.

Inset 6 – ICRP principles of radiation protection [26]

The three principles of radiation protection form the basis for the international, European and national legal and regulatory framework for the protection of man and the environment against ionising radiation.

1. *Justification.* Any decision that alters the radiation exposure situation should do more good than harm.
2. *Optimisation of protection* (also known as ALARA principle (as low as reasonably achievable)). The likelihood of incurring exposure, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors.
3. *Application of dose limits.* The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits specified by the [ICRP].

4.2 Description of the management system

Since the early 1980s, ONDRAF/NIRAS has gradually developed and implemented a management system aimed at protecting man and the environment from the risks presented by the radioactive waste that it takes charge of (Figure 12). This system currently comprises two major groups of operational activities, which are centralised in Mol–Dessel: short-term management activities (section 4.2.1) and medium-term management activities (section 4.2.2). ONDRAF/NIRAS also coordinates various types of activities with a view to ensuring the long-term management of waste (section 4.2.3). Two activities cross-cut the entire management system: the transport of waste and the acceptance of waste (section 4.2.4).

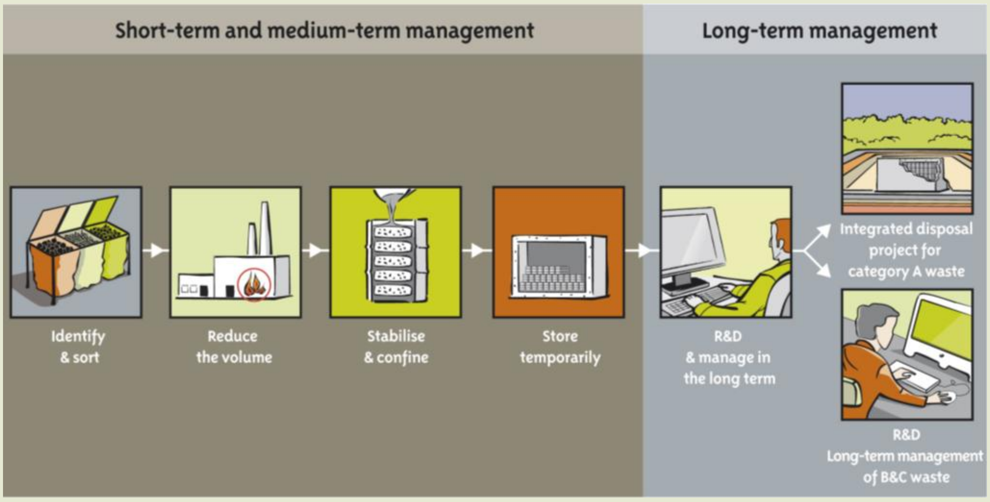


Figure 12 – Main steps in the radioactive waste management system developed by ONDRAF/NIRAS. The long-term management is not yet operational.

Ultimate radioactive waste: radioactive waste where further treatment, whether extraction of its recoverable material or a reduction in its polluting or dangerous nature, cannot reasonably be envisaged (in technical, radiation protection or financial terms).

The decision to declare a waste as ultimate waste can also be a political decision.

4.2.1 Short-term management

Short-term management activities, also called current management activities, are well in hand. They comprise two components: *management* activities *at the source*, which are the responsibility of radioactive waste producers, and *treatment and conditioning* activities.

4.2.1.1 Management at the source

Management at the source of radioactive waste begins with the prevention of radioactive waste by optimising industrial practices and limiting the volumes of materials satisfying the definition of radioactive waste. This limitation can be achieved in various ways, for example optimising dismantling techniques for out-of-service nuclear equipment and facilities, improving decontamination techniques, and using clearance possibilities. Radioactive waste producers are also responsible for sorting their waste in accordance with the directives of ONDRAF/NIRAS, ensuring that it meets the acceptance criteria, and clearly identifying its radioactive and non-radioactive contents in order for ONDRAF/NIRAS to take charge of it.

4.2.1.2 Treatment and conditioning

Treatment and conditioning activities are a series of mechanical, chemical and physical operations designed to convert non-conditioned radioactive waste into packages that satisfy the operational requirements for handling, transport, storage and long-term management. Waste treatment aims above all to concentrate the radioactivity as much as possible in order to reduce the volumes of materials to be considered as radioactive waste (Figure 13). It also aims to put these materials in a suitable physical and chemical state so that they can be conditioned. The conditioning of treated waste is generally performed by immobilising the waste in a matrix of glass, cement or bitumen within cylindrical metal packaging (Figure 13). This makes it possible to obtain a solid, compact material that is chemically stable and non-dispersible, where the radioactivity is confined within its mass.

Generally, treatment and conditioning activities are carried out centrally, as part of the ONDRAF/NIRAS management system. ONDRAF/NIRAS sub-contracts them to Belgoprocess, but assumes responsibility for them. In a minority of cases, some producers carry out their own treatment and conditioning activities, under ONDRAF/NIRAS control, or sub-contract treatment operations abroad, but recover the corresponding radioactive waste. Furthermore, conditioned waste has been or is still generated abroad as a result of the execution of reprocessing contracts for irradiated nuclear fuel (Figure 14).

Treated and conditioned radioactive waste is *ultimate* radioactive waste. This is particularly the case for all category B waste and category C reprocessing waste (see section 4.2.3 for the classification of conditioned waste).

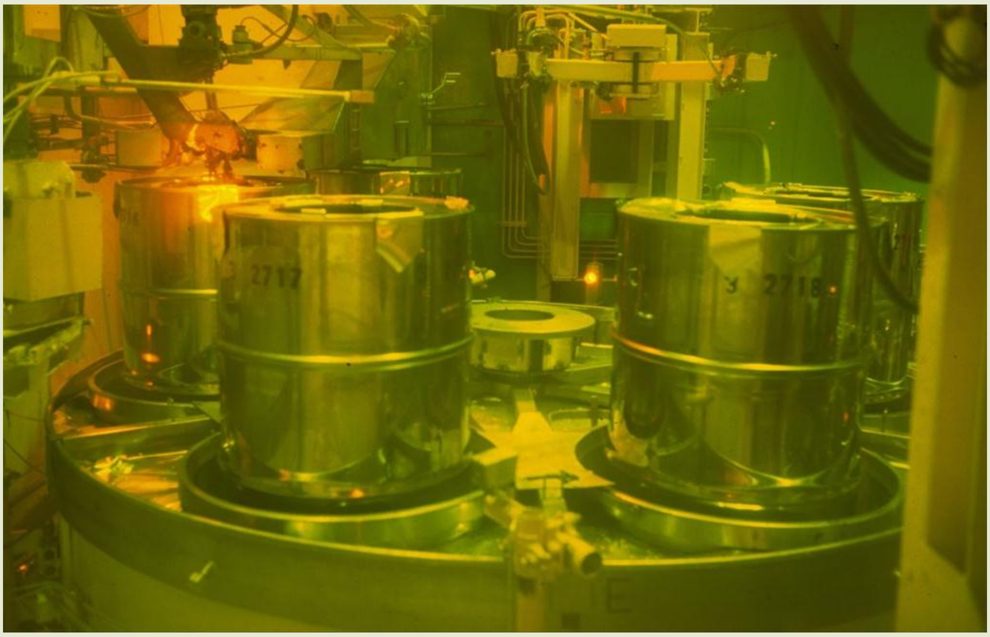


Figure 13 – Above, waste treatment by compaction (source: Belgoprocess and Bonsai Publicatiebureau) and section of a container containing cemented compacted waste slabs (source: Belgoprocess); below, conditioning of waste by bitumen immobilisation (source: Belgoprocess).

Figure 14 – Metal waste from the reprocessing of irradiated nuclear fuel (upper left) and the same waste compacted into slabs (lower left) then put into stainless steel containers (right) (source: AREVA NC).

4.2.2 Medium-term management

Medium-term management activities are well in hand. They include interim storage of conditioned waste in suitable buildings belonging to ONDRAF/NIRAS and operated by Belgoprocess, and monitoring pending a safe solution for its long-term management. Monitoring over time aims to control whether the conditioned waste packages remain compliant with the acceptance criteria that were applicable when they were accepted. The first monitoring control of selected accepted packages must take place three years after the packages are accepted, and subsequent controls at least every ten years during the storage period.

The storage buildings are designed to protect man and the environment from the potential harmful effects of the conditioned waste that they contain: their walls increase in thickness as the activity of the waste — low-level, medium-level, or high-level — increases, and all are shielded and, if necessary, fitted with waste handling systems operated remotely (Figure 15 and Figure 16).

The storage buildings for B&C waste are designed to have a lifespan of approximately 75 years, which may be extended to 100 years or more through regular maintenance and *ad hoc* replacement of equipment, as long as allowed by the provisions of the licences.

Figure 15 – External view of building 127 of ONDRAF/NIRAS operated by Belgoprocess designed for the storage of medium-level conditioned waste, and an internal view of one of its four bunkers. The waste is handled using a travelling crane controlled from a separate control room (source: Belgoprocess).

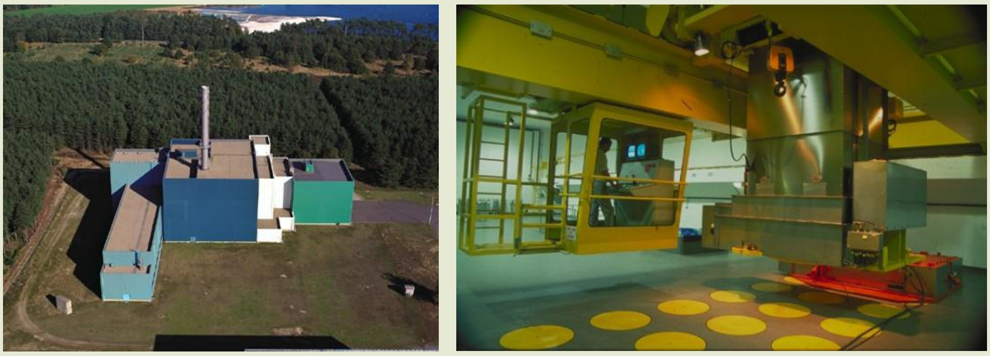


Figure 16 – External and internal views of building 136 of ONDRAF/NIRAS operated by Belgoprocess intended for the storage of high-level and medium-level conditioned waste. This building has been designed to withstand extreme external conditions such as earthquakes, explosions and military aircraft crashes. The containers of category C waste, which are handled remotely from a shielded control room, are stacked in silos equipped with a ventilation system designed to remove the heat that they emit. For each 450 kg container, this heat is initially comparable to that of a domestic electric radiator with a power of 2000W (source: Belgoprocess).

4.2.3 Long-term management

For long-term management, ONDRAF/NIRAS has adopted a classification consisting of three categories in accordance with international recommendations (Figure 17) [59]. This classification is based on the activity level and half-life of the radionuclides contained in the waste at the time of conditioning, which are indicators of the radiation risk that it presents and its duration. This has been complemented by the inclusion of a thermal parameter that considers the temporal change in waste activity level due to radioactive decay.

- *Category A waste* is short-lived low-level and medium-level conditioned waste which contains limited quantities of long-lived radionuclides. It presents a risk to man and the environment over several hundreds of years. It can be considered for surface disposal.

- *Category B waste* is low-level and medium-level conditioned waste containing long-lived radionuclides in such quantities that it presents a risk ranging from several tens to several hundreds of millennia for some of the waste. Its thermal power is potentially significant at conditioning, but it emits too little heat after its storage period to be classified in category C.

- *Category C waste* is high-level conditioned waste containing large quantities of long-lived radionuclides and which, like category B waste, therefore presents a risk ranging from several tens to several hundreds of millennia for some of the waste. Its thermal power on conditioning exceeds 20 $W{\cdot}m^{-3}$ and remains above this value well beyond the period currently considered for its storage.

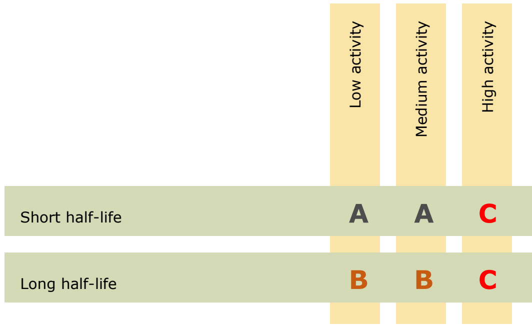


Figure 17 – Simplified representation of the classification of conditioned radioactive waste for long-term management. Category C waste emits a large amount of heat.

ONDRAF/NIRAS does not yet have an operational solution for the long-term management of the radioactive waste of which it takes charge, but a solution has been chosen at institutional level for category A waste.

- *Category A waste:* On 23 June 2006, the Council of Ministers opted for the surface disposal of this waste on the territory of the municipality of Dessel as part of an integrated project, and the disposal programme is currently in its project phase (Inset 7).

- *Category B&C waste:* Category B waste and category C waste are considered together for their long-term management because the risk that they present extends over similar timescales, from several tens to hundreds of millennia [11]. According to ONDRAF/NIRAS, they must be managed in the long term within the framework of a *centralised* management solution, i.e. a solution which is common to both and implemented at a single site.

  For almost 30 years, ONDRAF/NIRAS has conducted RD&D activities that are in line with international recommendations in terms of the long-term management of

[11] Category B waste comprises radium-bearing waste stored on the BP1 and BP2 sites of ONDRAF/NIRAS, operated by Belgoprocess. The long-term management of the waste will also be examined within the framework of a future management plan dedicated to the issue of radium-bearing waste (section 11.1). The prospect of such a plan does not call into question the considerations and conclusions relating to B&C waste developed in the current Waste Plan, and in particular category B radium-bearing waste.

high-level and/or long-lived conditioned waste, namely geological disposal (section 8.1). More specifically, the solution under study is disposal in poorly indurated clay (Boom Clay or Ypresian Clays) in a single facility located on Belgian territory. The promising nature of this solution, in terms of both safety and feasibility, has continually been strengthened since studies began. The validity of this solution has also been confirmed several times since 1976 by different commissions and working groups asked by institutional bodies to give an opinion on ongoing studies on the long-term management of B&C waste or issues related to Belgium’s energy policy. To date, these confirmations have not however been *formally* confirmed at federal level.

Although ONDRAF/NIRAS does not currently manage any irradiated fuel from the Doel and Tihange nuclear power plants, the resolution of the Chamber of 22 December 1993 which suspends the reprocessing of this fuel [40] also orders the Government *"to prioritise research and development, including within the international framework, so as to be able to implement the direct disposal of irradiated fuel, without reducing the current research programme in the field of deep disposal of reprocessing waste."* [translation ONDRAF/NIRAS]. ONDRAF/NIRAS has therefore had to give equal consideration to the study of geological disposal of both reprocessing waste and non-reprocessed irradiated fuel.

In practice, ONDRAF/NIRAS defines RD&D activities in terms of long-term management, assigns their execution to scientific partners (universities, research centres, etc.), engineering firms and industrial partners, in Belgium and abroad, and ensures knowledge integration with a view to drafting safety cases (section 9.2). It is actively involved in different types of international collaborations (Inset 8). SCK•CEN, which began RD&D activities in 1974, still makes a significant contribution to the ONDRAF/NIRAS programme. The large-scale demonstration projects and the experiments in the underground laboratory constructed in the Boom Clay under its site are assigned to EURIDICE, the economic interest grouping created by ONDRAF/NIRAS and SCK•CEN in 1995 (known at the time as the *PRACLAY economic interest grouping*) (section 8.1).

Inset 7 – Outline of the stepwise development of the programme for the long-term management of category A waste [60]

The category A disposal programme has developed in stages, following a decision-making process that began in 1998.

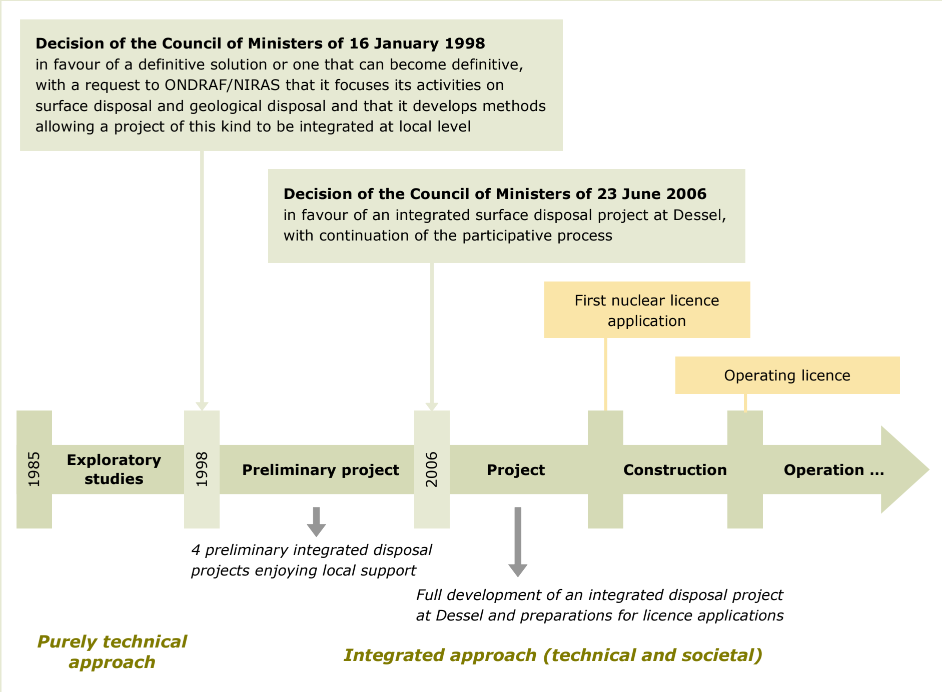
- On **16 January 1998**, the Council of Ministers opted *"for a solution that was definitive or could become definitive, and was progressive, flexible and reversible"* [translation ONDRAF/NIRAS] for the long-term management of category A waste and, in doing so, complied with the requirements of the ONDRAF/NIRAS legal and regulatory framework. In accordance with article 1 of the Royal Decree of 30 March 1981 [2], the long-term management must be such that the waste is placed in the long-term management facility without intention to retrieve: in other words, it must provide a solution that *can become definitive*. However, this does not exclude providing for the *possibility* to retrieve the waste relatively easily for a certain time. The 1998 decision, which defines the general direction to be followed for the long-term management of category A waste, conforms in spirit with the decision in principle that will be required based on the Waste Plan for the long-term management of B&C waste. It was based on a comparison, particularly from a safety and environmental perspective, of the various possible options for the long-term management of category A waste [61].

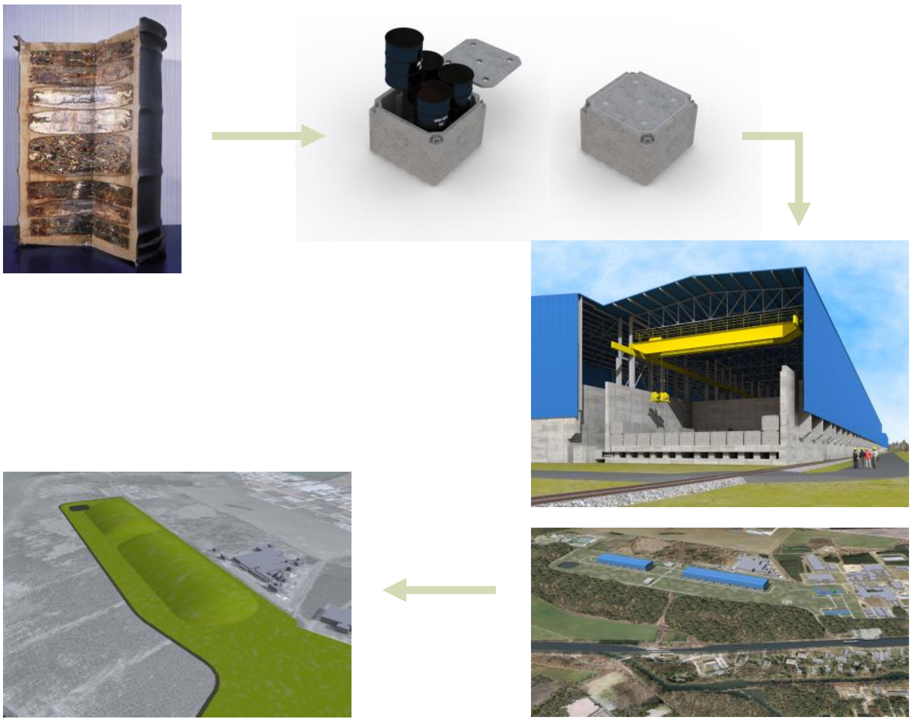
- On **23 June 2006**, the Council of Ministers opted for the surface disposal of category A waste on the territory of the municipality of Dessel, close to the existing centralised treatment, conditioning and storage facilities. This decision was made on the basis of four preliminary integrated disposal projects [1] developed within the partnerships established on a voluntary basis between ONDRAF/NIRAS and the municipalities of Mol and Dessel. The technical projects, developed from proposals provided by ONDRAF/NIRAS, formed part of larger projects, incorporating a significant societal aspect.

Meeting of the former STOLA partnership in Dessel (which has since become the STORA partnership).

- The category A disposal programme is **currently** in the project phase. ONDRAF/NIRAS is conducting detailed studies of the integrated project for surface disposal and preparing the safety case and the environmental impact assessment (*project-milieueffectenrapport* or *project-MER*, in accordance with regional Flemish legislation) needed for the licence applications (nuclear licence and environmental permits), with a view to starting to build the facilities. The detailed studies of the integrated disposal project are being conducted in close dialogue with the local populations in question, via the STORA (in Dessel) and MONA (in Mol) partnerships.

[1] A fifth preliminary integrated disposal project was developed as part of a partnership established between the municipalities of Fleurus and Farciennes and ONDRAF/NIRAS, but in the end was not proposed to the Government, in accordance with the decision of the municipal council of Fleurus.





The surface disposal of category A waste (project phase). The waste packages are placed in concrete caissons, which are then closed with a concrete lid. The voids in the caissons are filled with an immobilisation mortar, injected through holes in the lid, which results in the formation of monoliths. Using a travelling crane, these are placed in the side-by-side modules of the repository, which are protected by a fixed steel roof during the whole operation. After the modules are filled and a concrete top slab fitted, the roof is replaced with a permanent cover with low water permeability made up of various natural and artificial protection layers, forming tumuli.

Inset 8 – International collaboration for the long-term management of radioactive waste

ONDRAF/NIRAS actively contributes to various types of international collaborations relating to radioactive waste management: multilateral within the framework of the IAEA or the Nuclear Energy Agency (NEA) for example, and bilateral or multilateral with other national radioactive waste management agencies. In particular, ONDRAF/NIRAS signed a trilateral agreement with Andra (France) and Nagra (Switzerland), two agencies that are also studying clay formations as host formations for the geological disposal of radioactive waste. In 2010, it signed a research and development agreement with COVRA, its Dutch counterpart, on the possibilities for radioactive waste disposal in poorly indurated clays, and more particularly Boom Clay, on their respective national territories.

Research and development in terms of radioactive waste management across the world, at both national and international organisation level, follows an open approach. Knowledge and experience is shared, resources pooled and information published in scientific literature and subject to peer review. The Waste Plan and SEA are therefore based on scientific and technical knowledge that goes far beyond the knowledge acquired as part of the Belgian programme.

4.2.4 Acceptance (or quality assurance and control)

The radioactive waste taken charge of by ONDRAF/NIRAS must possess characteristics that are judged compatible with the requirements imposed by the subsequent steps in its management, such as transport, treatment and conditioning (for non-conditioned waste), storage and, ultimately, the solution foreseen for its long-term management. The ONDRAF/NIRAS reference solution for B&C waste is geological disposal in poorly indurated clay (Boom Clay or Ypresian Clays) (chapter 8).

The compatibility of waste with the requirements imposed by the subsequent steps in its management is ensured by the *acceptance system*, which can be seen as the *combination of a quality assurance system for the production chain of conditioned waste and a control system for this quality* (Figure 18).

There are three parts to the acceptance system.

- The establishment by ONDRAF/NIRAS of the *criteria* which non-conditioned and conditioned waste must satisfy for ONDRAF/NIRAS to take charge of it, as well as the establishment of how ownership of this waste is transferred to ONDRAF/NIRAS from the producers. The acceptance criteria have been established based on the *general rules* drawn up by ONDRAF/NIRAS in accordance with the provisions of the Royal Decree of 16 October 1991 [4] and approved by the competent authority on 10 February 1999. These also take into account the provisions of the licences issued by FANC for the transport of radioactive waste and the operation of treatment, conditioning and storage facilities for this waste. Once the solution for the long-term management of B&C waste is established, the acceptance criteria will be adapted to take into account the requirements specific to this solution and, subsequently, the provisions of the nuclear licence for construction and operation to be issued by FANC and needed so as to start implementing the solution.
- The *approval* by ONDRAF/NIRAS, in accordance with the provisions of the Royal Decree of 18 November 2002 [62], of the treatment and conditioning equipment and processes (i.e. the confirmation that these facilities and processes are suitable

for producing waste that complies with the applicable acceptance criteria), of the methods for determining the radiological content and physicochemical properties of non-conditioned and conditioned waste, and of the storage buildings.

- The *acceptance* by ONDRAF/NIRAS of the waste packages (conditioned or non-conditioned) delivered by producers, after the administrative and technical verification of their compliance with the applicable acceptance criteria. This is accompanied by payment from the waste producers of a tariff intended to cover the cost of its medium-term and long-term management (section 4.4) and the transfer of ownership of the waste to ONDRAF/NIRAS. In the case of delivery of non-conditioned waste, the waste is accepted a second time by ONDRAF/NIRAS after its conditioning by Belgoprocess. Waste already stored in ONDRAF/NIRAS buildings operated by Belgoprocess before the acceptance system came into force in early 1999 is also subject to this formal acceptance process.

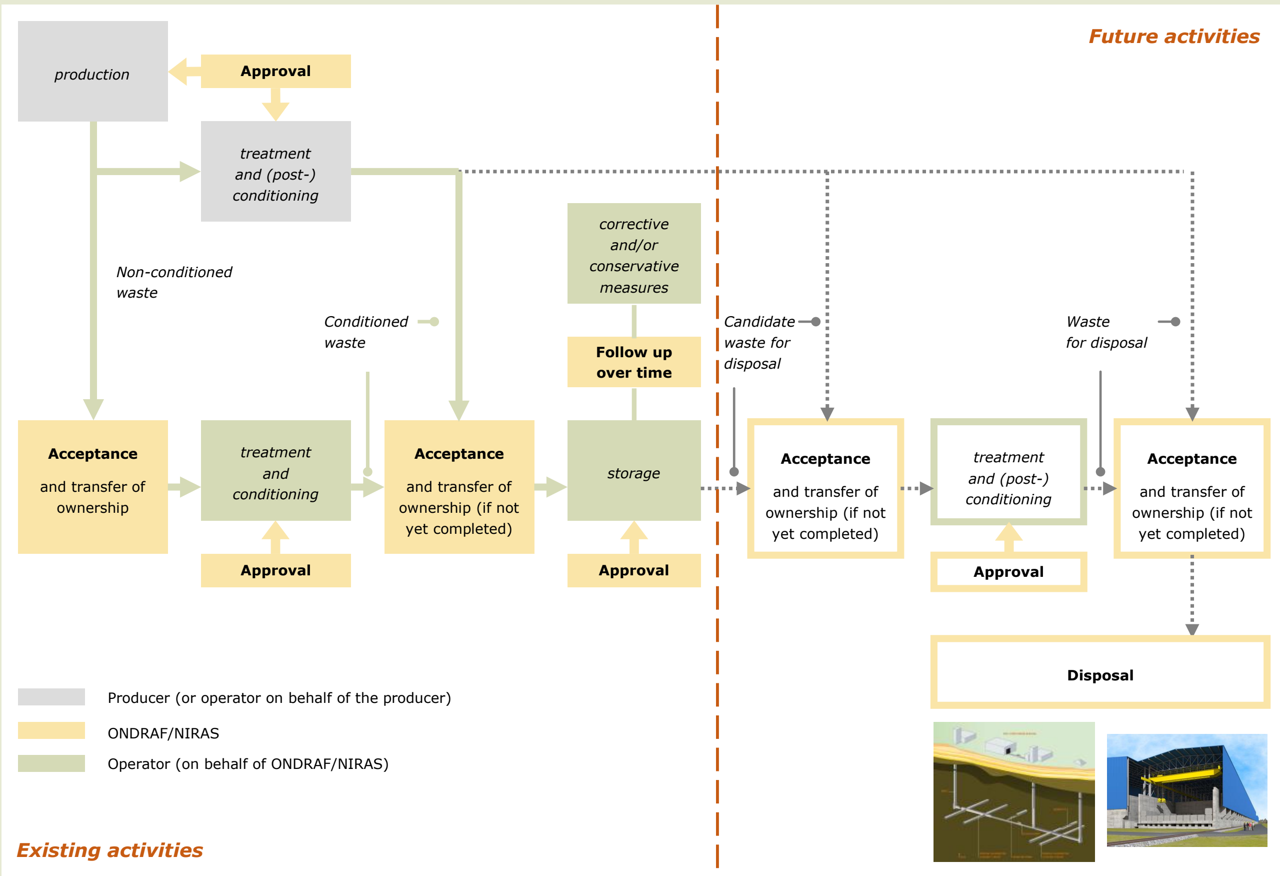


Figure 18 – Simplified diagram of the ONDRAF/NIRAS acceptance system for radioactive waste management. The system currently in force for the acceptance of non-conditioned and conditioned waste will be applied to waste for disposal.

The acceptance system is applicable to waste which is treated and conditioned in Belgium, as well as waste from reprocessing of Belgian irradiated fuel abroad which is treated and conditioned before being returned to Belgium. This waste results from reprocessing of commercial fuel of Synatom at The Hague (Inset 9) and from reprocessing of fuel of SCK•CEN's BR2 research reactor at The Hague and Dounreay (see also sections 3.2.1.1 and 3.2.1.2).

Radioactive waste from treatment abroad of equipment and contaminated materials of Belgian origin, which is returned to Belgium in a non-conditioned form, must, in accordance with the provisions of article 10 of the Royal Decree of 2002 [62], be accompanied by detailed characterisation files satisfying the ONDRAF/NIRAS requirements.

Inset 9 – The acceptance system applied to category C vitrified waste resulting from the reprocessing of Synatom's irradiated fuel by COGEMA (now AREVA NC)

ONDRAF/NIRAS acceptance of the category C vitrified waste from reprocessing of Synatom's irradiated fuel by COGEMA uses a similar system to that established for waste treated and conditioned in Belgium. However, since this system was developed before the general rules came into force, the acceptance criteria had to be officially confirmed subsequently [1].

Before using the vitrification process on a large-scale at The Hague, COGEMA commissioned an important work defining the composition of the glass and characterising it by the Atomic Energy Commission (CEA — which became the Atomic Energy and Alternative Energies Commission / *Commissariat à l'énergie atomique et aux énergies alternatives* in 2010, France), which resulted in the *specification* for vitrified waste in 1986. This specification guarantees a certain number of parameters that relate primarily to the chemical composition of the glass, its radionuclide content and its production method. It was approved by the French safety authorities, as well as by the competent institutions in the countries that sent irradiated fuel for reprocessing at The Hague, that is Belgium, Germany, Japan, the Netherlands and Switzerland. For Belgium, it was approved by ONDRAF/NIRAS in 1992. Shortly afterwards, an independent characterisation programme implemented at the request of COGEMA's clients confirmed that the data provided by COGEMA and its quality assurance and control system were reliable.

The *acceptance criteria* relating to containers of vitrified waste, established by ONDRAF/NIRAS in 1995–1996, are essentially based on the COGEMA specification. Similar documents have been produced by the foreign organisations, in particular Swiss, German and Dutch, concerned with the return of vitrified reprocessing waste.

COGEMA's vitrification process and facilities were *approved* by ONDRAF/NIRAS, along with the methods for determining the documented radiological and physicochemical properties of the containers of vitrified waste and the corresponding measurement facilities. This approval was announced in 1997 at the end of a three-step process:

- *review of COGEMA's technical qualification file,* describing the operation of the facilities and formalising and justifying all the measures taken to guarantee that the containers of vitrified waste would satisfy the applicable specifications and acceptance criteria;
- *verification*, with the assistance of Andra (the French equivalent of ONDRAF/NIRAS), *that the vitrification facilities comply with the conditions of the qualification file*;
- *detailed examination of the quality assurance and control system implemented by COGEMA* to guarantee that the containers of vitrified waste produced conform to specification. Given the considerable efforts required to develop analysis and measurement protocols for containers of vitrified waste, but which do not guarantee satisfactory results, COGEMA followed CEA's recommendation and opted for close monitoring of parameters involved in the production of vitrified waste and the assessment of uncertainty margins. This choice was accepted by the competent French authorities and ONDRAF/NIRAS, and confidence in the approach was confirmed by convergent results from independent analyses by CEA and JAERI (Japan Atomic Energy Research Institute) on a sample of high-level glass.

The approval and coming into force of the general rules on 10 February 1999 enabled ONDRAF/NIRAS to provide official confirmation for the acceptance criteria applicable to containers of vitrified waste produced by COGEMA.

The *acceptance* of packages of vitrified waste by ONDRAF/NIRAS, after administrative and technical verification of their compliance with the applicable acceptance criteria, is accompanied by a tariff payment from Synatom and a transfer of ownership of the waste from Synatom to ONDRAF/NIRAS.

[1] The acceptance system applicable to other conditioned waste resulting from the reprocessing of Synatom's irradiated fuel by COGEMA was, however, developed *before* the waste was conditioned.

4.3 Technical inventory of conditioned radioactive waste

In order to successfully fulfil its mission, ONDRAF/NIRAS must have a quantitative and qualitative inventory of all existing conditioned radioactive waste (including waste known as "nuclear liabilities", which are those of Belgoprocess, SCK•CEN and the National Radioelements Institute or *Institut national des radioéléments* or IRE [45]) and planned waste. This inventory is needed, in particular, to guide RD&D as best as possible, to optimise treatment and conditioning, to perform safety assessments, to design and size medium-term and long-term management facilities, and to ensure the creation of sufficient provisions to cover associated costs. This inventory is in three parts: a part relating to *quantities*, a *radiological* part and a *physicochemical* part. It is drawn up periodically, based on the knowledge of waste stored in the ONDRAF/NIRAS buildings operated by Belgoprocess and *declarations* from producers concerning their total future generation of waste from current production and dismantling waste. The last official technical inventory of ONDRAF/NIRAS dates from 2003 [63, 64, 65]. It is currently being updated and should be available in early 2012.

The main radioactive waste producers are the operators of the licensed nuclear facilities called class I or II in the general regulations on the protection against ionising radiation (Table 2).

- *Class I* includes nuclear reactors used to produce electricity or for scientific research, all other facilities within the fuel cycle, facilities that produce radionuclides on a large scale for nuclear medicine, and facilities that treat and condition radioactive waste or are used for its storage.
- *Class II* includes cyclotrons and other particle accelerators, storage facilities and facilities used in nuclear medicine and industrial radiography.

Table 2 – Current main operators of class I and II licensed nuclear facilities and main facilities and equipment.

Main nuclear operators	Main facilities and equipment
Activities related to the nuclear fuel cycle	
Fuel fabrication	
FBFC International (Dessel)	Fabrication facilities for UO_2 fuel assemblies from enriched UO_2 powders and fuel assembly facilities for MOX from rods of MOX fuel
Belgonucleaire (being dismantled, Dessel)	Fabrication facilities for rods of MOX fuel from UO_2 and PuO_2 powder
Electricity production (approximately 55% of total national production)	
Electrabel (Doel and Tihange) (Synatom owns the fuel)	7 commercial power plants (indication of the date of connection to the network and net installed capacity) Doel 1: August 1974 (392 MWe) (currently 433 MWe) Doel 2: August 1975 (433 MWe) Doel 3: June 1982 (1006 MWe) Doel 4: April 1985 (1008 MWe) Tihange 1: March 1975 (962 MWe) Tihange 2: October 1982 (1008 MWe) Tihange 3: June 1985 (1015 MWe) Treatment, conditioning and storage facilities, including storage facilities for irradiated fuel
Research	
Nuclear Research Centre (SCK•CEN) (Mol)	Reactors BR1, BR2, BR3 (being dismantled) and GUINEVERE [1], research and analysis laboratories
Institute for Reference Materials and Measurements (IRMM) (Geel)	1 linear accelerator, 1 Van De Graaff accelerator, measurement laboratories
Ghent University (Ghent)	Thétis reactor (awaiting dismantling), 1 cyclotron, linear accelerators
Five other Belgian universities	8 cyclotrons (including 2 attached to university hospitals), 2 linear accelerators
Radionuclide production for medical and industrial use	
National Radioelements Institute (IRE) (Fleurus)	Radionuclide production facilities
International Brachytherapy (Seneffe)	2 cyclotrons
Best Medical [2] (Fleurus)	2 cyclotrons (including 1 put out of service)
IBA Radio-Isotopes (Fleurus)	1 cyclotron
Radioactive waste management	
Belgoprocess (Dessel)	Treatment, conditioning and interim storage facilities (belonging to ONDRAF/NIRAS)
Umicore (Olen)	UMTRAP and "Bankloop" interim storage facilities
Various	
Maintenance of equipment used on various reactor sites in Europe	
Westinghouse (Nivelles)	Decontamination, repair and testing facilities and technical premises
Irradiation sterilisation of medical and surgical equipment, laboratory equipment and food	
Sterigenics (Fleurus)	Hundreds of high-level sealed sources

[1] Formerly the VENUS reactor
[2] Formerly MDS Nordion

4.3.1 2009 estimate of conditioned waste volumes

In 2009, ONDRAF/NIRAS updated its estimate of existing volumes of conditioned waste and future waste planned within the scope of the current nuclear power programme in order to satisfy a request from the GEMIX group (annex 7 in [66]), a group of national and international experts charged by the Royal Decree of 28 November 2008 [67] with conducting a study intended to present Government with one or more scenarios for the ideal energy mix for Belgium. (Also at the request of the GEMIX, ONDRAF/NIRAS carried out similar estimates for several scenarios to extend the operational period of nuclear power plants — section 10.2.2.)

The 2009 estimate takes into account the following two elements of institutional policy:

- the provisions of the Law of 31 January 2003 to phase out nuclear energy [68], which bans the construction and operation of new commercial nuclear power plants and orders the closure of the seven existing plants after 40 years of operation;
- the resolution by the Chamber of 22 December 1993 (section 4.2.3) [40], which requires ONDRAF/NIRAS to give equal consideration to the study of the geological disposal of reprocessing waste and that of non-reprocessed irradiated fuel. However, to date, the status of irradiated fuel (resource or waste) has not been established (section 10.2.1).

According to the ONDRAF/NIRAS 2009 estimate (situation as at 31 December 2008), which is not an official inventory, the volumes of category A, B and C waste to be managed by 2070, i.e. following dismantling of all existing nuclear facilities or facilities planned for construction as of 31 December 2008 [12], are as follows (Table 3, Figure 19 and, for an overview of the origins and characteristics of existing or planned B&C waste, annex A1) (annex 7 in [66], [69]).

- 69 900 m^3 of category A waste. About half of this waste arises from dismantling of commercial nuclear power plants, the total dismantling waste volume representing almost 75% of all category A waste. Category A waste represents less than 0.5% of the total activity of all waste.
- 11 100 or 10 430 m^3 of category B waste, depending on whether the current suspension of commercial irradiated fuel reprocessing is lifted or maintained. This waste is highly varied and arises mainly from research activities, nuclear fuel production, reprocessing of irradiated fuel (including in the Eurochemic pilot reprocessing plant), and dismantling of nuclear power plants and research and fuel production facilities. It represents about 2% of the total activity of all waste.
- 600 or 4 500 m^3 of category C waste, depending on whether the current suspension of commercial irradiated fuel reprocessing is lifted or maintained. This waste is vitrified waste resulting from reprocessing commercial irradiated fuel and non-reprocessed irradiated fuel declared as waste. It represents approximately 97.5% of the total activity of all waste. (Reprocessed commercial fuel represents 12% (tHM) of the total irradiated fuel generated by the nuclear power programme as provided by the law to phase out nuclear energy, which is 40 years of operation for the seven Belgian nuclear power plants.)

12 The 2009 estimate does not therefore include operational and dismantling waste from the future SCK•CEN MYRRHA (Multi-purpose hybrid research reactor for high-tech applications) research reactor, which is currently being developed.

Table 3 – Estimate of the quantities and activities for category A, B and C waste to be managed by 2070 [66, 69]. The scenarios for resuming or definitively abandoning reprocessing are mutually exclusive.

Principal types of conditioned waste to be managed		2009 estimate (40 years of operation of power plants)		
		vol. [m^3]	act. α [Bq] *	act. βγ [Bq] *
Category A waste (for the record)	Total	69900	$< 2 \cdot 10^{12}$	$< 5 \cdot 10^{16}$
Category B&C waste	***if reprocessing resumes (for all fuel, including MOX)***			
Category B: Commercial nuclear power plants				
Current production waste				
Electrabel operational waste		260	$7.0 \cdot 10^{10}$	$3.0 \cdot 10^{15}$
Synatom reprocessing waste		940	$2.3 \cdot 10^{16}$	$1.2 \cdot 10^{18}$
Dismantling waste from Electrabel reactors		900	$4.7 \cdot 10^{12}$	$3.2 \cdot 10^{17}$
Doel 1 and 2 and Tihange 1 renovation waste		n.a.	n.a.	n.a.
Category B: Others				
Current production waste (including Eurochemic waste)		7500	$1.0 \cdot 10^{16}$	$6.0 \cdot 10^{17}$
Dismantling waste		1500	$< 1 \cdot 10^{15}$	$< 1 \cdot 10^{16}$
	Total	11100	$3.4 \cdot 10^{16}$	$2.1 \cdot 10^{18}$
Category C: Commercial nuclear power plants and research reactors				
Reprocessing waste	Total	600	$6.0 \cdot 10^{17}$	$4.1 \cdot 10^{19}$
Category B&C waste	***if reprocessing is definitively abandoned***			
Category B: Commercial nuclear power plants				
Current production waste				
Electrabel operational waste		260	$7.0 \cdot 10^{10}$	$3.0 \cdot 10^{15}$
Synatom reprocessing waste		270	$2.8 \cdot 10^{15}$	$1.4 \cdot 10^{17}$
Dismantling waste from Electrabel reactors		900	$4.7 \cdot 10^{12}$	$3.2 \cdot 10^{17}$
Doel 1 and 2 and Tihange 1 renovation waste		n.a.	n.a.	n.a.
Category B: Others				
Current production waste (including Eurochemic waste)		7500	$1.0 \cdot 10^{16}$	$6.0 \cdot 10^{17}$
Dismantling waste		1500	$< 1 \cdot 10^{15}$	$< 1 \cdot 10^{16}$
	Total	10430	$1.4 \cdot 10^{16}$	$1.1 \cdot 10^{18}$
Category C: Commercial nuclear power plants and research reactors				
Reprocessing waste		70	$3.6 \cdot 10^{16}$	$3.6 \cdot 10^{18}$
Synatom irradiated fuel (UO_2 and MOX)		4430	$2.2 \cdot 10^{18}$	$4.0 \cdot 10^{19}$
	Total	4500	$2.2 \cdot 10^{18}$	$4.4 \cdot 10^{19}$

n.a.: Not applicable

*: For category A waste, the activity given is that at the end of 2007. For category B waste, the activity given is that at time of conditioning (or is the estimated activity in the case of planned waste). For category C waste, the activity given is that 50 years after removal from the reactor.

Figure 19 – Above: dismantling of the Eurochemic pilot reprocessing plant (source: Belgoprocess and Bonsei Publicatiebureau); below: dismantling of part of the BR3 research reactor (source: SCK•CEN).

4.3.2 Related issues regarding the 2009 estimate

In addition to the suspension of commercial irradiated fuel reprocessing and the status of non-reprocessed irradiated fuel (section 10.2.1), ONDRAF/NIRAS has identified several issues, the answers to which are not a matter solely for ONDRAF/NIRAS and which are likely to impact the estimated volumes of conditioned waste:

- the potential extension of the operational period of nuclear power plants (section 10.2.2);
- the possible transfer of category A waste to category B (or *vice versa*), resulting from the requirements of the future nuclear licence for construction and operation of the surface disposal facility for category A waste (section 10.2.3);

- the potential declaration by the producers concerned of all or part of their enriched fissile materials and plutonium-bearing materials as waste (section 10.2.4);
- possible modifications to the inventory of category B radium-bearing waste (sections 10.2.5 and 11.1).

In order to be able to fulfil its radioactive waste management mission, ONDRAF/NIRAS must receive an answer to these issues (section 10.2). The current lack of an answer does not, however, call into question the possibility of making a decision in principle for the long-term management of B&C waste, as confirmed by the SEA Advisory Committee in its opinion on the draft Waste Plan and the SEA [33].

4.4 Financing of the management system

In accordance with the "polluter pays" principle, ONDRAF/NIRAS must charge the beneficiaries of its services, in this case the radioactive waste producers, for its costs, estimated at cost price.

The cost of radioactive waste management can be divided into three items:
- short-term management activities,
- RD&D activities and "societal participative process" type activities,
- medium-term and long-term management activities.

4.4.1 Short-term management activities

The short-term management activities of radioactive waste are financed by the waste producers within a framework of agreements with ONDRAF/NIRAS that provide for revised tariffs every five years. Since 1996, these contracts have been based on a capacity reservation system that stipulates that each major producer undertakes to pay ONDRAF/NIRAS an agreed fraction of the fixed costs for the facilities and the variable operating costs for the management of its waste as it is accepted by ONDRAF/NIRAS. In practice, the producers pay their share of the fixed costs according to a contractual schedule and pay the tariff amounts corresponding to the treatment and conditioning of their non-conditioned waste as it is accepted by ONDRAF/NIRAS. Furthermore, ONDRAF/NIRAS activities directly related to its acceptance system (mainly establishing the general rules and acceptance criteria, as well as approving treatment and conditioning facilities — section 4.2.4) are financed through specific contracts with producers.

4.4.2 RD&D activities and "societal participative process" type activities

RD&D activities, which focus primarily on long-term management, are financed by waste producers in proportion to their planned waste production, within a framework of agreements with ONDRAF/NIRAS.

Financing for the "societal participative process" type activities that ONDRAF/NIRAS intends to set up as soon as possible and which will take place throughout the entire decision-making process supporting the development and implementation of the chosen solution for long-term management of B&C waste (chapter 9) is still to be organised, and then confirmed at institutional level.

4.4.3 Medium-term and long-term management activities

Financing for the medium-term and long-term management of radioactive waste must cover the cost of technical activities and, in the case of an integrated disposal project such as, for example, that for the disposal of category A waste, the costs of so-called "associated" conditions which allow the integrated project in its entirety to provide added value for the local populations concerned. Some mechanisms must indeed ensure equity between populations that serve the general interest by accepting waste on their territory and the rest of the community. Technical costs are covered by payments made by waste producers into a centralised fund, the *long-term fund*. The cost of associated conditions is covered by another mechanism, the *medium-term fund*.

In addition to the provisions created by ONDRAF/NIRAS for the medium-term and long-term management of the radioactive waste of which it takes charge (section 4.4.3.1), producers also create provisions with a view to their future transfers of radioactive waste to ONDRAF/NIRAS (section 4.4.3.2).

4.4.3.1 Provisions created by ONDRAF/NIRAS: sufficiency and availability

The provisions intended to cover the technical costs for the medium-term and long-term management of radioactive waste transferred to ONDRAF/NIRAS are paid by waste producers into the long-term fund, created in accordance with the provisions of article 16 of the Royal Decree of 30 March 1981 as amended and placed under its responsibility. An insolvency fund has also been created pursuant to the provisions of the same decree. Finally, financing for integrating a final repository into a local community is governed by the Law of 29 December 2010 [6], which complements article 179, § 2, of the Law of 8 August 1980 relating to ONDRAF/NIRAS by allowing it to create a medium-term fund for this purpose. The Law of 2010 also introduces the concept of long-term fund into the Law of 1980, already present in the Royal Decree of 30 March 1981.

Long-term fund

The objective of the long-term fund is *"to cover all the costs and investments that are needed in order to store radioactive waste and build, operate and close radioactive waste disposal facilities, and ensure their institutional control, in accordance with the licences issued to perform these activities"* [translation ONDRAF/NIRAS] [6]. It does not aim to cover the cost of potentially retrieving the disposed waste, which is impossible to evaluate in the distant future.

Taking the mechanism of pension funds as an example, ONDRAF/NIRAS chose to base the long-term fund, operational since early 1999, on a capitalisation system. Radioactive waste producers contribute to it every time they transfer new waste to ONDRAF/NIRAS, after ONDRAF/NIRAS has verified that the waste satisfies the established acceptance criteria, all in accordance with the contractually stipulated provisions.

The funding mechanism for the long-term fund is such that it guarantees in principle that ONDRAF/NIRAS will be able to cover its fixed costs eventually and will enable it to cover its variable costs as they arise. It applies to the producers who have signed agreements with ONDRAF/NIRAS for the collection of their waste and is based on the following three fundamental elements:

- *contractual quantities*: each of the main radioactive waste producers notifies ONDRAF/NIRAS of its total waste production programme, enabling ONDRAF/NIRAS to share its fixed costs between them;
- *tariff payment*: each producer pays a contribution into the long-term fund (volume of waste × tariff applicable to this waste), based on the total cost (fixed and variable costs, including margins for technological and project risks) for medium-term and long-term management of the waste taken charge of by ONDRAF/NIRAS;
- *contractual guarantee*: each of the main producers agrees to pay into the long-term fund at least the amount of the fixed costs relative to the capacity reservation that it has made.

Small producers without agreements are subject to an *all-in* tariff. The main producers are responsible for any shortfall in contributions to the long-term fund.

The provisions under which the long-term fund must operate are established in the agreements, called "collection contracts", between ONDRAF/NIRAS and the waste producers. The ONDRAF/NIRAS working assumptions and the contractual quantities given by the main producers can be revised on an *ad hoc* basis, so as to adjust the financial terms to changes in waste production forecasts, development work in terms of long-term management, and a changing economic context.

The main economic assumptions for the current agreements are as follows.

- Category A waste: this will be subject to surface disposal, at a single site. This assumption was confirmed by the Government decision of 23 June 2006.
- B&C waste: the seven existing nuclear power plants will be operated for 40 years, in accordance with the Law of 31 January 2003 on the gradual phasing out of nuclear energy, all irradiated fuel (including MOX fuel) will be reprocessed, and the waste will be subject to geological disposal at a single site as soon as is reasonably possible and in any case after at least 60 years of interim surface storage for category C waste.

ONDRAF/NIRAS currently manages the long-term fund on the basis of an investment strategy defined by its Board of Directors. The Advisory and Audit Committee for the long-term fund (comprised of representatives from ONDRAF/NIRAS, the Belgian State, Synatom and Electrabel) follows up and verifies its management. According to ONDRAF/NIRAS, the characteristics of the long-term fund are such that they ensure the satisfactory availability of financial resources corresponding to the amounts paid by producers [42].

The mechanism of the long-term fund does not however make it possible to deal with certain special cases, such as the possible insolvency of the main waste producers, or to pass on to a producer any underestimate of costs for the long-term management of its waste after it has delivered its *last* waste to ONDRAF/NIRAS and made the corresponding tariff payments to the long-term fund. ONDRAF/NIRAS is therefore currently reviewing what additional financing mechanisms can be set up in order to cover special cases and prevent the Belgian State, and therefore the citizen, being forced to make up for any shortfall in provisions.

Insolvency fund

The insolvency fund, implemented in 1992, is mainly intended to finance services for radioactive waste management and dismantling of nuclear facilities that are not covered following the bankruptcy or insolvency of certain financially liable entities who are implicitly identified as being the financially liable entities for facilities other than class I nuclear facilities. The insolvency fund also covers the cost of managing sources, as stated in the general regulations on the protection against ionising radiation, declared as orphans and waste by FANC and transferred to ONDRAF/NIRAS by FANC for management (section 3.2.1.4). It does not cover services resulting from the bankruptcy or insolvency of financially liable entities who have performed industrial activities relating to radium extraction (sections 10.2.5 and 11.1.1) and the use of natural sources of radioactivity (work activities, section 11.2).

The insolvency fund is managed in the same way as the long-term fund. It is financed by a reserve of 5% included in the cost of services invoiced to producers by ONDRAF/NIRAS, which is due or not depending on whether the available resources in the insolvency fund satisfy certain criteria.

Medium-term fund

The medium-term fund [6] is *"intended to cover the cost of the associated conditions that have been approved, on the one hand, by the municipal council(s) of the municipality(ies) that has (have) made possible the creation and continuity of societal support for the establishment of a repository, by developing and maintaining a participative process or any other method or process, existing or to be designed, achieving the same result and, on the other hand, on the Organisation's proposal, by the Federal Government. These costs are generated with a view to creating and maintaining the required societal support to ensure the integration of a radioactive waste repository in a local community."*

"The medium-term fund is financed by the integration contribution from radioactive waste producers. The integration contribution is calculated based on the total capacity of the repository and the respective total quantities of waste from producers intended for disposal."

"The obligation to contribute to the medium-term fund starts when the radioactive waste repository has been subject to a definitive and binding licence for construction, in accordance with the Law of 15 April 1994 relating to the protection of man and the environment against the hazards of ionising radiation and establishing the Federal Agency for Nuclear Control, and a licence to build and, if necessary, an environmental permit in accordance with the applicable regional legislation."

"Provided that their individual share does not exceed 3% of the total capacity of the repository, public research institutions that mainly draw on the budget of the State, a Community or a Region, and public or private institutions active in the healthcare sector are exempt from paying the integration contribution. As long as their individual share of capacity does not exceed the aforementioned threshold, occasional producers of radioactive waste are also exempt." [translation ONDRAF/NIRAS]

4.4.3.2 Provisions created by the producers: sufficiency and availability

In Belgium, there is currently no general legislation obliging radioactive waste producers to have provisions to cover the cost of managing their waste, including that from the future dismantling of their nuclear facilities, and ensure the availability of the corresponding financial resources. This cover is subject to general accounting legislation and laws and royal decrees that are often relatively specific and established on a case-by-case basis. In particular, the Law of 11 April 2003 [70], as amended, makes Synatom responsible for ensuring that the costs for dismantling commercial nuclear power plants and managing the resulting radioactive waste are covered, along with the costs of managing irradiated fuel and the funds which constitute their exchange value in accordance with specific rules. Every three years, Synatom must also draft a report describing the basic characteristics used to create the provisions. This report must be submitted to the Commission for Nuclear Provisions created by this same law.

The creation of provisions by radioactive waste producers for the dismantling of their nuclear facilities and the management of their radioactive waste and the sufficiency of these provisions are analysed and assessed by ONDRAF/NIRAS as part of its nuclear liabilities inventory mission. The assessment as to the sufficiency of the provisions created by Synatom relies on the opinion that ONDRAF/NIRAS is bound to provide to the Commission for Nuclear Provisions to enable it to draw up its three-yearly resolutions on the existence and sufficiency of the provisions. The drafting of this three-yearly opinion requires ONDRAF/NIRAS

- to examine the scenarios and strategies which Synatom has used as a basis for estimating the dismantling costs for nuclear power plants and the management of the resulting radioactive waste, as well as the management of irradiated fuel, in order to ensure that they give rise to realistic and conservative estimates;
- to verify the sufficiency of existing or planned provisions to cover the estimated costs.

The Law of 11 April 2003, as amended, does not however contain adequate terms to ensure the timely availability of financial resources corresponding to the provisions.

The analysis of the existence, sufficiency and availability of nuclear provisions made by ONDRAF/NIRAS as part of its nuclear liabilities inventory mission resulted in the formulation of a series of recommendations on this subject, in particular [42]:

> *"The existing legal and regulatory framework should be added to in order to minimise, or at least limit, the risk that the State should become a substitute for defaulting financially liable entities to cover their nuclear costs.*
>
> *ONDRAF/NIRAS recommends that a clear and consistent legal and regulatory framework is established, organising cover for nuclear costs. This framework must impose the creation of sufficient provisions and contain appropriate terms to ensure their availability in a timely manner."* [translation ONDRAF/NIRAS]

These recommendations have been agreed by the ONDRAF/NIRAS supervisory authority, which in early 2009 gave ONDRAF/NIRAS the mission of establishing a proposed legal and regulatory framework that satisfies this recommendation [71].

5 Scope of the Waste Plan and the need for a decision in principle as soon as possible for the long-term management of B&C waste

The Waste Plan focuses in particular on waste for which is it *necessary* and *possible* to make a decision in principle as soon as possible with regard to the direction to follow for its long-term management. This is category B and C waste.

The Waste Plan only considers existing and planned (mainly within the scope of the current nuclear power programme) waste. It does not therefore consider the long-term management of waste from the operation of new commercial or research reactors.

5.1 Scope of the Waste Plan

The Waste Plan focuses in varying degrees on all types of waste that ONDRAF/NIRAS must manage or which it is likely to manage eventually (Table 4). This waste corresponds to the materials highlighted on the green and grey rows in Table 1 in section 3.2.4.

- Above all, the Waste Plan is intended to allow a decision in principle on the long-term management of B&C waste, a decision which is *needed* as soon as possible (section 5.2) and which is *possible* (section 5.2 and particularly chapters 7 and 8).

  The possible long-term management options and the management solution recommended by ONDRAF/NIRAS are discussed in the 2nd part of the Waste Plan. According to ONDRAF/NIRAS, this solution must be a *centralised long-term management solution*, i.e. be common to all B&C waste and be implemented at a single site. However, this does not mean that it should be implemented in the same location where the short-term and medium-term management activities of ONDRAF/NIRAS are centralised (the BP1 and BP2 sites of ONDRAF/NIRAS in Dessel and Mol respectively, operated by Belgoprocess).

- The Waste Plan only mentions the long-term management of category A waste for the record, insofar as, on 23 June 2006, the Council of Ministers opted for the surface disposal of this waste on the territory in the municipality of Dessel, as part of an integrated project, and that this is currently in its project phase (Inset 7 in section 4.2.3 and [60]).

- The Waste Plan does not propose a strategy for the long-term management of radioactive waste from remediation operations, as per the meaning in the general regulations on the protection against ionising radiation and which, therefore, target radioactive pollution from past and work activities. In fact, the definition of a long-term management strategy for radioactive waste from the remediation of radioactive pollution (remediation operations that are already completed, that are decided but are still to be performed, and that could still be decided), as well as remediation operations related to work activities, require that several institutions at federal (ONDRAF/NIRAS, FANC) and regional level first develop a joint vision with regard to the remediation operations to be carried out and the long-term management of the resulting radioactive waste. One or more management systems, complementary to the existing centralised management system, will then have to be developed. They will probably be *decentralised* in whole or in part, i.e. the waste will be at least partly managed on the sites where it is currently held.

ONDRAF/NIRAS has identified a series of related issues regarding the long-term management of B&C waste (chapter 10) and the issue of remediation (chapter 11), the answers to which are not a matter solely for ONDRAF/NIRAS. These issues do not call into question either the need for a decision in principle as soon as possible for B&C waste, or the management solution that it recommends. The issues likely to impact the long-term management of B&C waste must however be clarified by the parties concerned in the coming years. Chapter 11 also presents a future long-term management plan dedicated to the specific issue of radium-bearing waste.

As a decision-making tool intended to support the Waste Plan and the decision in principle that it is aiming for, the SEA focuses solely on the long-term management of B&C waste. In accordance with the Law of 13 February 2006 [12], ONDRAF/NIRAS did not have to draw up an SEA for the long-term management of category A waste [13]. (In the 1990s, ONDRAF/NIRAS had already compared the possible options for the long-term management of category A waste, in particular from a safety and environmental perspective [61].) Furthermore, it would be premature to envisage impact studies for the long-term management of radioactive waste from remediation operations.

[13] Article 19 of the Law of 13 February 2006 specifies that the obligation to draw up an SEA is applicable to plans and programmes where the first formal preparatory action is later than 21 July 2004, as well as plans and programmes where the first preparatory action is prior to this date, but which are adopted after 21 July 2006. The programme for the long-term management of category A waste is not subject to the obligation to draw up an SEA since its first preparatory action — the decision by the Council of Ministers of 16 January 1998 — was prior to 21 July 2004 and since it was adopted on 23 June 2006, which is before the deadline of 21 July 2006.

Table 4 – Scope of the Waste Plan. The Waste Plan focuses on B&C waste, for which there is not yet an institutional policy regarding its long-term management (as represented by the highlighted box) and for which such a policy is needed and can be defined. [✓: yes; ×: no]

	A waste	B waste	C waste (reprocessing)	Irradiated fuel from research reactors (B)	Irradiated fuel from nuclear power plants (C)	Enriched fissile materials and plutonium-bearing materials (B)	UMTRAP and "Bankloop" waste	Waste from future remediation operations
	Waste given for the record	**Waste targeted by the Waste Plan: a decision in principle about its long-term management is necessary and can be made**					Waste where the long-term management must be subject to a consultation (chapter 11) [1]	
ONDRAF/NIRAS responsible for the management?	✓	✓	✓	× , unless declared as waste by the owner	× , unless declared as waste by Synatom	× , unless declared as waste by the owner	eventually, ✓	× , unless decision by FANC
Treatment and conditioning provided?	✓	✓	✓	×	× [2]	×	*Will be incorporated into the management system(s) to be developed. (Some waste from UMTRAP could have to be incorporated into category B.)*	*Will have to be managed within the management system(s) to be developed. (Some could have to be incorporated into category A or category B.)*
Storage provided?	✓	✓	✓	✓ [3]	✓ , on power plant sites, by Electrabel	✓ , on owner sites		
RD&D for the long-term management?	✓	✓	✓	✓ [4]	✓	× [5]		
Long-term management policy?	✓	×	×	×	×	×		
Long-term management solution implemented?	in preparation	×	×	×	×	×		
Financing mechanism?	✓	✓	✓	✓	✓	✓	× [6]	×

[1]: the future management plan dedicated to the entire issue of radium-bearing waste does not call into question the considerations and conclusions relating to B&C waste developed in the current Waste Plan

[2]: current studies by Synatom and ONDRAF/NIRAS

[3]: ONDRAF/NIRAS provides storage for irradiated fuel from SCK•CEN's BR3 research reactor

[4]: no dedicated national RD&D programme for long-term management, but bibliographic follow-up

[5]: no dedicated national RD&D programme for long-term management, no producer having informed ONDRAF/NIRAS of its intention to transfer such materials as waste to date

[6]: there is the beginning of a provision by Umicore, the sufficient nature of which cannot be assessed as long as there is no clear view of the type of long-term management solution to be implemented

5.2 Need for a decision in principle as soon as possible for B&C waste

An institutional policy for the long-term management of B&C waste is essential for providing a *framework* for the management of the waste. Furthermore, the existence of such a policy would strengthen the position of ONDRAF/NIRAS in relation to all parties (institutional, political, commercial, etc.) concerned with radioactive waste management.

Several types of arguments combine to confirm the *need* for a decision in principle as soon as possible for the long-term management of B&C waste:

- the existence of international recommendations for countries with radioactive waste to define a management policy for the waste, as well as the existence of such a policy in a number of countries (section 5.2.1);
- the existence of documents pertaining to federal authorities that refer to the need to define a long-term management policy for B&C waste (section 5.2.2);

- the requirements of sound management by ONDRAF/NIRAS, including the associated equity arguments (section 5.2.3);
- the wish of Belgian and European public opinion that the issue of the long-term management of high-level waste is resolved by current generations rather than being passed on to future generations (section 5.2.4).

The Waste Plan also shows that all the elements needed to make a decision in principle are *available*. Indeed, ONDRAF/NIRAS has assessed the possible long-term management options from the environmental and safety, technical and scientific, financial and economic, and societal and ethical angles, with this assessment being consolidated by the results of the SEA (chapter 7). It is able to recommend a long-term management solution — *geological disposal in poorly indurated clay (Boom Clay or Ypresian Clays)* (chapter 8) — which can provide robust protection to man and the environment, is feasible, is based on solid technical and scientific grounds, satisfies the principles of intragenerational and intergenerational equity, can be financed in accordance with the "polluter pays" principle, and for the development and implementation of which it has drafted an outline of decision-making process. The solution of geological disposal is subject to broad consensus among radioactive waste management organisations and safety authorities at national and international level. In other words, ONDRAF/NIRAS is able to propose *a solution that is technically sufficiently mature to be subject to a decision.* Moreover, the validity of this solution has also been confirmed several times since 1976 by different commissions and working groups asked by institutional bodies to give an opinion on current studies on the long-term management of B&C waste or issues related to Belgium's energy policy (section 8.1.1).

A decision in principle *as soon as possible* is all the more justified since at least one or two decades will be needed to refine the studies relating to the chosen management solution, develop sufficient societal support for this solution, select a site for its implementation, prepare the licence applications, construct the facility, and begin industrial operations. So, assuming that the decision in principle would be made as soon as possible and would confirm the solution recommended by ONDRAF/NIRAS, category B waste will only be disposed of from 2035–2040 at the earliest and category C waste from 2080 at the earliest (section 9.2).

It must be noted that the technological prospects in terms of the development and industrial implementation of advanced nuclear technologies are currently such that a long-term management solution will remain essential for category B waste and existing and planned category C reprocessing waste (section 7.2.2.1).

5.2.1 Existence of international recommendations referring to the need for a radioactive waste management policy

The existence of clear national policies for long-term management is central to the international recommendations on radioactive waste management. Moreover, the great majority of OECD countries with one or several commercial nuclear power plants have defined such a policy for their B and/or C waste (Inset 10 at the end of section 5.2.3). In all cases this policy is for geological disposal.

- 2002: Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [8], ratified by Belgium in 2002

  "In accordance with the provisions of Article 30, each Contracting Party shall submit a national report to each review meeting of Contracting Parties. This report shall address the measures taken to implement each of the obligations of the Convention. For each Contracting Party the report shall also address its:
  i) spent fuel management policy;
  ii) spent fuel management practices;
  iii) radioactive waste management policy;
  iv) radioactive waste management practices;
  v) criteria used to define and categorize radioactive waste."
  (Article 32, 1)

- 2008: Council of the European Union, Resolution on Spent Fuel and Radioactive Waste Management, adopted 16 December 2008 [72]

  "i) each Member State is responsible for its own spent fuel and radioactive waste management policy. […]"

  "ii) it is essential that each Member State should put in place a national spent fuel and radioactive waste management plan. […]"

- 2009: Summary Report of the Third Review Meeting of the Contracting Parties to the Joint Convention [73]

  "15. Although significant progress has been made since the last Review Meeting, much still needs to be done to meet the following challenges: i) The implementation of national policies for the long-term management of spent fuel, including disposal of high level waste and/or spent fuel; […]"

  "37. […] In order to fulfil this goal, the actions of the Contracting Parties and as a consequence their reports to the next Review Meeting should include the following issues:
  – Development of a comprehensive regulatory framework;
  – The effective independence of the regulatory body;
  – Implementation of the strategies with visible milestones;
  – Funding to secure waste management;
  – Education and recruitment of competent staff and employees;
  – Geological repositories for high level waste."

2009: Letter sent by FANC to its supervisory authority regarding the report on the third review meeting of the contracting parties to the Joint Convention [77] — Annex 1 regarding peer review of the Belgian system

"With regard to the follow-up of the observations from the previous meeting (2006), the report [of the peer review] mentions that: ONDRAF/NIRAS is still awaiting a decision in principle about the management of highly active waste and spent fuel […]" [translation ONDRAF/NIRAS]

- 2009: IAEA publication *Policies and Strategies for Radioactive Waste Management* [74]

  > *"Every country should have some form of policy and strategy for managing its spent fuel and radioactive waste. Such policies and strategies are important; they set out the nationally agreed position and plans for managing spent fuel and radioactive waste, and are visible evidence of the concern and intent of the government and the relevant national organizations to ensure that spent fuel and radioactive waste are properly taken care of."*

- 2010: Document *Contribution to the Stakeholder Consultation Process for a possible EU Instrument in the Field of Safe and Sustainable Spent Fuel and Radioactive Waste Management by the European Nuclear Energy Forum* [75], formed on the initiative of the European Commission and which brings together, in particular, the Governments of the 27 Member States, the European Parliament and the European Economic and Social Committee, the nuclear industry, electricity consumers and civil society

  > *"4.2 The Government of each MS should develop and implement an appropriate national spent fuel and radioactive waste management policy to protect humans and the environment from harmful effects arising from ionising radiation. Furthermore, radioactive waste and spent fuel should be managed in such a way that it will not impose undue burdens on future generations. The national policy should also consider the preservation of natural resources, the optimisation of the disposal concept and the waste volumes as well as the radiotoxicity of the wastes. Further, the policy should guarantee the necessary continuity and flexibility for the implementation of the programme to be able to cope with changes in society and evolution in science and technology, as well as to prevent inefficient allocation of human and/or financial resources."*

  > *"4.3 The national spent fuel and waste management policy should be empowered through a legislative, regulatory and organisational framework in a timely manner. Societal support and trust is essential for the successful implementation of geological repositories. Early involvement in the decision making, both at national and local level, is a key issue in this context, as is also a credible demonstration of the system safety."*

2009: The international recommendations became best practices, as demonstrated in the opinion formulated in 2009 by EDRAM [76], an international association bringing together eleven national radioactive waste management agencies.

> *"EDRAM Members therefore share the view that States who do not yet have a national policy for the long-term management of their high-level and/or long-lived waste should establish one as soon as possible, as well as an adequate funding mechanism. The possibility of future changes in context (knowledge and understanding, legal and regulatory framework, society, etc.) advocates in favour of management policies that allow for a flexible decision-making process, starting with a strategic decision, often called "decision-in-principle", and aimed to guide necessary developments according to a sound application of the precautionary principle."*

5.2.2 Existence of documents at federal level referring to the need for a decision in principle

Several documents pertaining directly or indirectly to the federal authorities refer to the need to define a long-term management policy for B&C waste.

- 2003: The international review of the SAFIR 2 report (safety assessment and feasibility interim report 2, summarising the knowledge accumulated at the end of 2000 in terms of geological disposal in poorly indurated clay in Belgium, namely Boom Clay and to a much lesser extent Ypresian Clays — see also section 8.1.1 and [16, 17]) concludes that there is a need for a long-term management policy for radioactive waste [10]. This review was performed in 2002–2003 at the Government's request by an international team under the auspices of the NEA.

  > *"In order to focus future work, it is considered essential that the policy and the regulatory framework in Belgium be developed further. The views of ONDRAF/NIRAS on the societal dimension of developing a repository are innovative and very valuable. They will provide important input to policy development."*

- 2004: The request sent to ONDRAF/NIRAS on 19 November 2004 by its supervisory authority for it to assess all possible strategies in terms of the long-term management of B&C waste refers to the need to choose a management solution [11].

  > *"With reference to our discussion […], I think it would be appropriate for your organisation to develop a work programme with societal considerations in this area, like the programme that was developed for category A waste, with the aim of involving the various stakeholders in establishing a progressive decision-making process, within the framework of a dialogue structure agreed with them.*
  >
  > *Such a work programme should allow the study of all possible long-term management strategies, as well as possible participative procedures, with the drafting of a* Strategic Environmental Assessment *representing an important step in this process. The results of such a study should allow a decision to be made with regard to the option to be considered ultimately and set the conditions which the option must satisfy.*
  >
  > *Consequently, I would ask you […] to submit a practical proposal to me for the work programme and the dialogue structure […]. Such a dialogue must above all allow the direct involvement of the various stakeholders in the development of a progressive decision-making process in terms of the long-term management of the radioactive waste concerned, which is recognised by all parties in question."* [translation ONDRAF/NIRAS]

- 2006: The Law of 13 February 2006, which imposes that the adoption of the programme of ONDRAF/NIRAS for the long-term management of radioactive waste be preceded by an environmental assessment of the recommended management solution and reasonable alternative solutions, also refers to the need to choose a management solution [12].

- 2009: The letter sent by FANC to its supervisory authority regarding the report on the third meeting of the contracting parties to the Joint Convention informs the supervisory authority that Belgium still had not made the decision in principle that it was already lacking three years ago [77].

  > *"With regard to the follow-up of the observations from the previous meeting (2006), the report [of the peer review] mentions that: ONDRAF/NIRAS is still awaiting a decision in principle about the management of highly active waste and spent fuel […]"* [translation ONDRAF/NIRAS]

- 2009: The final report by the GEMIX group, created by royal decree to conduct a study on the ideal energy mix for Belgium [67], highlights the need for a definitive solution and, therefore, a decision in principle for the management of B&C waste [66].

  > *"all the necessary efforts must be made, taking into account technological developments, to reach a definitive solution for the management of type B and C radioactive waste that is acceptable from a societal perspective."* [translation ONDRAF/NIRAS]

5.2.3 Sound management and associated equity arguments

There needs to be a policy for the long-term management of B&C waste, not only to allow optimum and proper management of the waste, but also for equity reasons.

5.2.3.1 Enable ONDRAF/NIRAS to fulfil the final step in its management mission for B&C waste

Article 179, § 2, of the Law of 8 August 1980 [1] requires ONDRAF/NIRAS to provide a final destination for radioactive waste. Without a decision in principle with regard to this destination, ONDRAF/NIRAS cannot fulfil this part of its public service mission, but wishes to do so as soon as possible.

5.2.3.2 Enable ONDRAF/NIRAS to optimise the short-term and medium-term management of B&C waste

Although the short-term and medium-term management of B&C waste is carried out routinely and *does not pose any safety concerns*, various aspects of this management are based on an assumption as to the final destination of the waste: geological disposal in poorly indurated clay (Boom Clay or Ypresian Clays). As long as this assumption is not confirmed, and may even be set aside in favour of another type of final destination, ONDRAF/NIRAS is not able to optimise various aspects of its current management system for B&C waste and improve its assessment and control of the costs.

- ONDRAF/NIRAS is not currently able to confirm the definition of the acceptance criteria which B&C waste must satisfy for its long-term management. If these criteria need to be amended, certain characteristics of the current treatment and conditioning processes or the packages used could also have to be modified.

The volume of conditioned waste likely to require corrective measures in order to satisfy amended acceptance criteria will be greater, the later the final destination of the waste is known. This is because the production of conditioned waste packages will continue in accordance with the unconfirmed acceptance criteria in the meantime.

As long as the definition of the acceptance criteria is not confirmed, the monitoring controls of the stored waste packages over time are not optimal, since they are carried out on the basis of unconfirmed criteria.

- ONDRAF/NIRAS cannot currently optimise the corrective measures that need to be taken when the monitoring controls, over time, identify waste packages in which defects have appeared. So, whilst some package types are designed to retain their integrity under storage conditions over 75 years, others, among the oldest, have a much shorter lifespan.

  An example of packages requiring corrective measures is that of low-level and long-lived bituminised waste conditioned by SCK•CEN in the 1980s with a view to disposal at sea (for example lines c-14 and c-15 in annex A1). At that time, campaigns for disposal at sea were organised every year under the international control of the OECD, and conditioned waste packages were therefore only stored for a year at most. The only requirements that needed to be satisfied were those related to the handling of the waste and the fact that it had to sink to the bottom of the ocean once dumped. However, in 1984 Belgium agreed to the 1983 international moratorium on disposal at sea and ratified the definitive ban on such disposal in 1994, and these packages have been stored in ONDRAF/NIRAS buildings operated by Belgoprocess ever since.

  In 2000, Belgoprocess noticed that some packages of bituminised waste initially intended for disposal at sea were presenting phenomena such as swelling and overflow of the bitumen. All packages of this type were therefore temporarily placed in larger overpacks, which made it possible to continue to monitor their behaviour while awaiting a solution for their long-term management. It is this solution that will determine how these packages need to be definitively repackaged, even reconditioned so that they do not present a risk to man and the environment, including in the long term.

5.2.3.3 Enable ONDRAF/NIRAS to optimise its activities with a view to the long-term management of B&C waste

The current activities of ONDRAF/NIRAS with a view to the long-term management of B&C waste assume that the management solution to be implemented will be the solution that it recommends. As long as this solution is not confirmed, and may even be set aside, at an institutional level,

- ONDRAF/NIRAS cannot focus its RD&D activities in terms of the long-term management of B&C waste with full knowledge of the facts;
- the financing method for the long-term management of B&C waste is affected by uncertainty, in that neither the type of management solution to be implemented nor the timing and conditions attached to it have been established.

5.2.3.4 Avoid loss of knowledge and know-how due to breaks in continuity in the activities

Given that the development and implementation of solutions for the long-term management of radioactive waste extend over decades, continuity of knowledge and know-how, particularly in terms of knowledge about waste, RD&D and industrial know-how, is an essential, yet inconspicuous factor in the safety of the solutions developed and their implementation. It is important to maintain this continuity of knowledge and know-how.

- A clear perspective with regard to the solution to be implemented for the long-term management of B&C waste is essential to avoid the risk of a gradual reduction in national knowledge and expertise in terms of RD&D and of an increasingly large gap opening up between the Belgian programme and similar programmes abroad which are moving forward. Belgium, which was one of the pioneering countries in RD&D on geological disposal in the 1970s (section 8.1.1), has been overtaken by many countries; many have defined a long-term management policy for their waste (Inset 10 at the end of section 5.2.3) and some of them are in principle only 10 or 15 years away from beginning the industrial operation of a geological repository.

  The risk of a loss of knowledge and expertise within the Belgian programme is a threat whatever long-term management solution is ultimately chosen, if the choice has been postponed for too long.

  An obvious example of the impact of the lack of application prospects for maintaining knowledge is that of the gradual antipathy towards mining engineering studies caused by the progressive closure of Belgian coal mines, the last ones having been closed almost 20 years ago.

- A schedule allowing the continuity of the industrial activities of ONDRAF/NIRAS, i.e. allowing the progressive transfer of teams involved in the construction and operation of the surface disposal facility for category A waste towards the implementation of the solution chosen for the long-term management of B&C waste, is essential in limiting the risk of losing industrial know-how. Given that these operations relating to the surface disposal facility would be most intensive during the 2030–2045 period, and considering the time that is still needed to bring a solution for the long-term management of B&C waste to the implementation stage, this management solution must be chosen without delay.

5.2.3.5 Satisfy ethical equity principles

Compliance with the ethical principles of intragenerational and intergenerational equity requires the establishment of a policy for the long-term management of B&C waste as soon as possible.

- Compliance with the *intragenerational equity* principle obliges society as a whole to avoid keeping the municipalities where B&C waste is currently stored as a temporary measure (Mol and Dessel) in a *fait accompli* situation, a storage situation which is being extended *de facto* without any clarity about its total duration. These municipalities must be allowed to know how long the current situation will last and what type of long-term management solution will then be implemented. The same question will be asked with more intensity if

ONDRAF/NIRAS is required to provide storage for non-reprocessed irradiated fuel declared as waste by Synatom or if it has to provide storage for additional reprocessing waste (assuming that the reprocessing suspension is lifted) and there is no prospect for its long-term management.

- Compliance with the *intergenerational equity* principle obliges the current generation to do everything in its power to develop and implement a solution for the long-term management of B&C waste, so as to avoid passing on the responsibility for management in its entirety, including all the associated burdens, to future generations, but simultaneously suggests giving them a freedom of choice with regard to the management of the waste that they inherit.

5.2.3.6 Satisfy the "polluter pays" principle

The application of the "polluter pays" principle in the long-term management of radioactive waste requires producers to bear the cost, at cost price, of the management of *their* waste.

In accordance with the mechanism of the long-term fund (section 4.4), each producer pays ONDRAF/NIRAS the tariff amount applicable to the waste that it transfers to ONDRAF/NIRAS, following acceptance.

The necessity to know the final destination for the waste so as to be able to calculate the charges to be imposed on the producers was highlighted by ONDRAF/NIRAS and its Board of Directors in the report on the 2003–2007 nuclear liabilities inventory [42].

> *"Closure of the long-term management system for radioactive waste:*
>
> *Estimating the costs for the long-term management of radioactive waste means knowing its final destination. The cost of radioactive waste repositories is indeed a major component in the long-term management cost.*
>
> *ONDRAF/NIRAS recommends that the Government, in application of the precautionary principle and when it considers that it has the necessary elements, decides on the management methods (final destination, phasing, decision-making process) for medium-level and high-level and long-lived waste (category B and C waste)."* [translation ONDRAF/NIRAS]

Furthermore, on the basis of current agreements, when a producer reaches the end of its waste delivery programme, ONDRAF/NIRAS is not able to recover from that producer any increase in the estimated charges for the management of its radioactive waste. Adjustments may then have to be taken care of by remaining producers and/or the Belgian State and, therefore, the citizen, which in both cases contravenes the "polluter pays" principle. Consequently, ONDRAF/NIRAS is examining what additional financing mechanisms could be set up in order to cover this type of situation.

The earlier the solution for the long-term management of B&C waste is agreed and further specified, the easier it will be for ONDRAF/NIRAS to estimate the charges related to this management and thus recover them from all producers.

Inset 10 – Outline of the situation at 31 July 2011 in terms of an institutional policy for the long-term management of B and/or C waste in different OECD countries with one or several nuclear power plants (see also SEA, annex B) (see [78] for a general summary of the situation in these countries)

Countries with an operational long-term management solution:

- Since 1999, the **United States** has operated the WIPP facility (Waste Isolation Pilot Plant), built in a salt layer near Carlsbad, in New Mexico, for the disposal of their category B military waste. This facility is currently the only geological disposal facility in use in the world. The policy for the long-term management of B&C waste is currently being reviewed, following the political decision to shut down the project for the geological disposal of irradiated fuel at Yucca Mountain. Geological disposal of this waste, as soon as possible, is still the recommended solution in the preliminary report by the Blue Ribbon Commission set up by the President of the United States after the shut down of the Yucca Mountain project to give opinions, assess the alternatives and make recommendations for the management of the back-end of the nuclear fuel cycle in the United States [79]. An independent committee, the U.S. Nuclear Waste Technical Review Board, advises the United States Congress and the Energy Secretary on the technical issues related to the management of this waste.

Countries with an institutional policy for long-term management:

All countries with an institutional policy for the long-term management of their B and/or C waste have opted for geological disposal. Nine examples are described below. In the most advanced countries, such as Finland, France, Sweden and Switzerland, the policy relating to this management and its gradual implementation, as well as, in several cases, the follow-up of this implementation have been sanctioned by one or several legislative acts.

- **Canada** is going to dispose of its radioactive waste in several geological repositories. The licence application to construct a geological disposal facility for category A&B waste was presented to the federal regulation authorities in April 2011. The host rock at the selected site, Kincardine, is limestone under clay. The repository is not expected to be constructed before 2013, becoming operational in 2018 at the earliest [80].

  For irradiated fuel, Canada opted for an adaptive, stepwise process for geological disposal. Furthermore, only those local communities that have expressed *a priori* an interest in accommodating a repository will be taken into consideration when assessing geological potential. The site selection process began in May 2010 [81].

- In **Finland**, radioactive waste management is governed by the "Nuclear Energy Law". This law, passed in 1987 and amended in 2004, requires the final disposal of radioactive waste related to nuclear energy production on Finnish territory. It specifies that irradiated fuel is radioactive waste. In May 2001, Parliament adopted the decision in principle (made by the Government in December 2000) to establish a geological disposal facility for irradiated fuel from existing reactors within a crystalline formation. (The only formations suitable for accommodating a geological repository in Finland are crystalline formations.) The disposal licence was extended so that the repository could accept irradiated fuel from two new licensed reactors, following decisions in principle ratified in 2002 and 2010 respectively. The licence application for construction of the repository is expected to be submitted in 2012 for it to become operational in 2020. The construction of a characterisation facility at the Eurajoki site, where the repository will be located, began in 2004. This facility precedes the repository itself.

- In **France**, the "Bataille Law" passed in 1991, established the research programmes for radioactive waste management and, in particular, the management of B&C waste, and set the milestones for subsequent steps. This law complemented and amended the Environmental Code, passed in 1975, which specifies the regulations applicable to all waste generated in France. The Law of 30 December 1991 established a National Review Board (*Commission nationale d'évaluation* or CNE), comprised of scientists whose assignment is to assess the results of research programmes. Every year, the CNE drafts an evaluation report [82] which the Government sends to Parliament (Parliamentary Office for Evaluating Scientific and Technology Options).

  In 2006, after 15 years of research (provided for in the "Bataille Law"), the "Waste Law" completed the legal framework. This law establishes a national management plan for radioactive materials and waste [83] and creates a research and work programme combined with a schedule for its implementation. It requires the submission of a licence application for a geological disposal facility for B&C waste in 2015 and the start of industrial operations at this repository, subject to this licence, in 2025. The "Waste Law" specifies that the licence application for a geological repository must relate to a geological layer which has been subject to studies using an underground laboratory (which is, in practice, the Callovo-Oxfordian clay layer, within which the Meuse/Haute-Marne laboratory at Bure is based). This same law (or the decrees implementing the law) stipulates that the Government will present a draft law establishing the reversibility conditions and that a public debate should be held before the submission of the licence application for a geological disposal facility.

- **Germany** dictates that all its radioactive waste must be disposed of in geological formations. The licence to construct the geological disposal facility for category A&B waste in Konrad, an old iron mine (limestone) located under a clay cover, was granted in 2002 and confirmed in 2007. The repository, currently under construction, should be operational in 2017–2018.

  For heat-emitting waste (category C waste), Germany is concentrating on salt as a host formation. The Gorleben site, where the host rock is a salt dome, has been studied, notably through an underground facility, from 1977 to 2000. It is currently the subject of a preliminary safety analysis requested by the Federal Government in 2010 to assess its capacity to accommodate category C waste. The results of this analysis are expected in late 2012.

  The old Asse salt mine, which was an underground research laboratory for the geological disposal of category A&B waste in the 1960s and 1970s, was used at the same time for the experimental disposal of radioactive waste, in accordance with the mining law. This practice was banned in 1978, when it appeared that the site was not safe. Research activities continued there until 1995. The mine changed its status in early 2009 and is now governed by nuclear law. The federal authorities have just given the authorisation to start the first retrieval phase of the waste with a view to its subsequent management.

- **Japan** chose geological disposal for category C waste in 2000. This choice was extended to category B waste in 2007. The site selection process began in 2002 and is still in progress.

- In 1984, the **Netherlands** has opted for the geological disposal of B&C waste, after storage for 100 years (and this, in order to have a sufficient quantity of waste that the disposal is economically viable). The host formations considered are salt and clay. The Netherlands has just restarted an RD&D programme related to disposal in clay [84, 85].

- The **United Kingdom** Government chose geological disposal for the long-term management of B&C waste in 2006, without expressing a preference for a particular host formation. The site selection process is currently in progress. At the moment, three local communities have expressed an interest without any commitment on their part. The Committee on Radioactive Waste Management (CoRWM) was set up in 2003 to provide independent advice to the United Kingdom Government [86].

- In **Sweden**, the "Law on Nuclear Activities", passed by Parliament in 1984, requires owners of nuclear reactors to develop a definitive solution for the long-term management of their radioactive waste. The research and development programme of SKB, a company formed by these owners to manage their waste, is reviewed by the Swedish Nuclear Safety Authority every three years and must be approved by the Government. Irradiated fuel is considered as waste and will be disposed of in a geological disposal facility within a crystalline formation, for which the Forsmark site was chosen by the Government in 2009. (The only formations suitable for accommodating a geological disposal facility in Sweden are crystalline formations.) The licence application to build this repository was submitted to the Swedish authorities in March 2011. Its construction should begin in 2015, and it should become operational in 2025. The Government is advised by an independent body, the Swedish National Council for Nuclear Waste (KASAM).

- In **Switzerland**, the "Nuclear Energy Act", in effect since 2005, stipulates geological disposal as the long-term management solution for all Swiss radioactive waste. The requirements to be satisfied and the procedure to be followed for the search for sites for geological disposal are defined in a sectoral plan "Disposal in Deep Geological Layers", adopted in 2008 by the Federal Council. The safety criteria laid down by the sectoral plan led to the choice of clay as the host formation for the disposal of B&C waste [87]. In 2010, the safety authorities approved the three geological areas (all situated in Opalinus Clay) proposed by the National Cooperative for the Storage of Radioactive Waste (Nagra). In autumn 2011, the Federal Council must decide which areas will be considered for the remainder of the selection procedure.

The geological disposal of military waste in the WIPP facility,
in a salt layer in New Mexico (United States) (source: USDOE).

View of the Meuse / Haute-Marne underground research
laboratory built in clay in France (source: Andra).

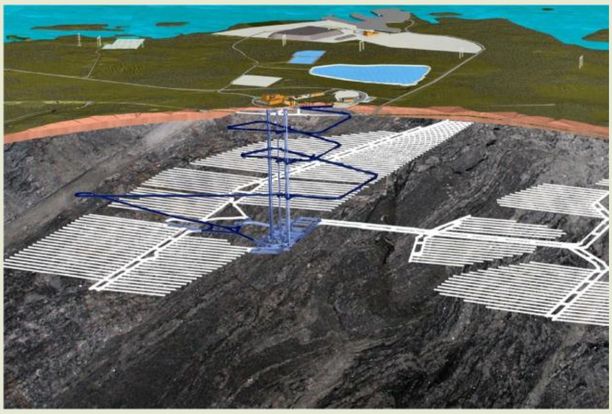


Diagram of the Finnish ONKALO characterisation facility built in
crystalline rock (dark blue) and the planned extension (light blue)
as well as the planned repository for irradiated fuel (white)
(source: Posiva).

Works in the ONKALO characterisation facility, in Finland
(source: Posiva).

Investigations in the Aspö underground laboratory in Sweden,
to determine the feasibility of the disposal of irradiated fuel in a
crystalline rock (source: SKB).

Works in the Mont Terri underground research laboratory,
built in clay in Switzerland (source: Nagra).

Countries with a wait-and-see type institutional policy:

- Spain opted for the storage of its B&C waste over 60 years.

Countries without an institutional policy for long-term management:

- Belgium, Italy, Slovak Republic, etc.

Progress of geological disposal projects in ten OECD countries

Country	Types of waste	Host formation	Site selection	Construction licence	Commissioning scheduled for...
Canada	A&B	limestone under clay	site chosen (Kincardine)	requested in 2011	2018
	C	choice still open	procedure in progress	unspecified	unspecified
Finland	C	crystalline rock	site chosen (Eurajoki)	*application scheduled for 2012*	2020
France	B&C	clay	procedure in progress (region of the Bure laboratory)	*application scheduled for 2015*	2025
Germany	A&B	limestone under clay	site chosen (Konrad)	2007	2017–2018
	C	salt	Gorleben site being studied	unspecified	unspecified
	A&B	salt	Asse	licence for waste retrieval granted in 2011	not applicable
Japan	B&C	choice still open	procedure in progress	unspecified	unspecified
The Netherlands	B&C	salt or clay	unspecified	unspecified	after 2100
United Kingdom	B&C	choice still open	procedure in progress	unspecified	unspecified
United States	military B	salt	site chosen (Carlsbad, New Mexico)	granted	WIPP, operational since 1999
	C	recommendation in favour of geological disposal (to be confirmed)			
Sweden	C	crystalline rock	site chosen (Forsmark)	requested in 2011	2025
Switzerland	B&C	clay	procedure in progress	approximately 2028	approximately 2040

5.2.4 Wish of public opinion that radioactive waste management is not passed on to future generations

According to the European Commission's Eurobarometer on radioactive waste in June 2008 [88], European Union citizens in general (93%) and Belgian citizens in particular (96%) consider that a solution for the long-term management of high-level waste must be found now, rather than pass this unresolved problem on to future generations.

This desire was also apparent in the ONDRAF/NIRAS dialogues and the interdisciplinary conference organised by ONDRAF/NIRAS in the first half of 2009 prior to writing the Waste Plan and the SEA [29], as well as during the citizens conference organised by the King Baudouin Foundation in late 2009 – early 2010 [31].

2

Part 2

Description, assessment and comparison of the possible options for the long-term management of B&C waste and solution recommended by ONDRAF/NIRAS

6 Brief description of the management options considered

The Waste Plan considers options that allow the management system for B&C waste to be closed in the sense that they can become definitive (section 6.1), as well as options that cannot become definitive (section 6.2) and the option that consists in maintaining the status quo, also called the zero option (section 6.3) (Figure 20). These options are considered generically. In other words, their definition and assessment (chapter 7) are not related to a specific site. These options were subject to a strategic assessment within the scope of the SEA.

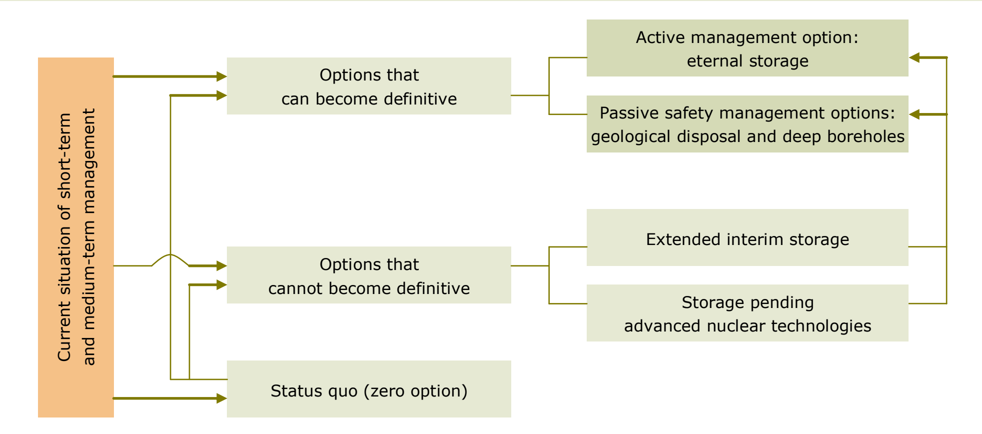


Figure 20 – The various management options considered in the Waste Plan. Sooner or later, the status quo and the options that cannot become definitive would need an option that can become definitive.

Other options, considered at one time or another in the past by one or more countries, are described in the SEA, but were immediately rejected as they are in violation of international treaties or conventions to which Belgium is a signatory and/or the Belgian legal and regulatory framework and/or do not provide adequate safety guarantees. They are only mentioned in the Waste Plan for the record (Inset 11 in section 6.1.2).

Closure: "completion of all operations at some time after the emplacement of spent fuel or radioactive waste in a final storage facility. These operations include the final engineering or other work required to bring the facility to a condition that will be safe in the long term" (Law of 2 August 2002, article 2)

Safeguards: provisions made at international level to ensure that the States that are signed up to the non-proliferation treaty do not divert or acquire nuclear materials with the intention of manufacturing nuclear weapons. These provisions comprise a verification system that includes declaration (accountancy) obligations for operators and verification (control) obligations for the regulator. The IAEA is responsible for this verification system. For the European Union, there is a system of additional nuclear guarantees (Euratom Safeguards). In Europe, verification activities are conducted jointly by the IAEA and Euratom. *(The rest of the text uses "safeguards" as a generic term covering non-proliferation, guarantees and verification activities.)*

The options assessed and those rejected are more or less comparable to the options that have been studied in other countries [89, 90, 91, 92] (see also SEA, annex B). The SEA Advisory Committee confirms [33] that the presentation in the SEA of the approaches planned in other countries *"allows an understanding that the choice of possible options is consistent with the approaches adopted in the other countries concerned with radioactive waste and irradiated fuel of a similar nature."* [translation ONDRAF/NIRAS]

Excluding the option that consists in maintaining the status quo, the different management options considered can all be envisaged within an exclusively national framework or within a multinational framework (see SEA, annex D). By definition, a national option is implemented in Belgium; due to the reciprocity principle, a shared option involving several countries could be implemented in Belgium, just as it could be implemented in another country that is party to the multinational management agreement that must then be signed.

6.1 Options that can become definitive

Various options that can become definitive can be considered for the long-term management of B&C waste. They can be divided into two groups, depending on the chosen management strategy.

- *Active management* provides protection of man and the environment indefinitely, i.e. as long as it must be ensured (for several hundreds of millennia for B&C waste), through human actions. Insofar as the waste remains within relative reach of man, the options relying on active management require control measures, such as surveillance and access restrictions to the site(s), and enable close and long-lasting control of safety.
- *Passive safety management* provides protection of man and the environment without human interventions being necessary once the management facility is closed*. The options relying on passive safety management do not therefore need to be indefinitely controlled after complete closure in order to be safe: they are intrinsically safe as long as they have been correctly developed, optimised and implemented. However, the lack of need for controls does not mean the absence or impossibility of controls. Moreover, controls in terms of safety, security and safeguards will be imposed by the regulatory framework, and ONDRAF/NIRAS intends to maintain the additional controls that would be required by society, for example in order to minimise the risk of human intrusion, over a period to be agreed. It will be up to each generation to decide on the knowledge and resources that it would want to transfer to the next generation to enable it to maintain these controls (see also section 8.1.3.2).

6.1.1 Active management option

The only possible active management option that can become definitive is *eternal storage*. Eternal storage (see SEA, section 7.2.1.1) is seen as being the almost theoretical repetition of storage and repackaging or reconditioning steps for waste, over hundreds of millennia. It requires the design and construction of storage facilities (surface, near-surface or deeper — Figure 21) capable of protecting man and the environment for periods that range from 100 to 300 years by means of periodic controls and maintenance and periodic verifications of the integrity of the waste containers that these facilities contain. To maintain the protection of man and the environment over time, new storage facilities must periodically be constructed at the end of the lifespan of the old facilities and the waste must be repackaged or reconditioned, then transferred to these new facilities, which gradually increases the total quantity of waste to be stored (Figure 22). Indeed, the conditioning matrix and container surrounding the waste are the first confinement barriers for the radioactivity and must consequently be replaced when they no longer comply with the provisions of the licences. Moreover, the storage site must also be controlled. Protection of man and the environment therefore permanently relies on human actions: an eternal storage facility cannot be abandoned as is. Of course, this repetitive sequence of actions may be interrupted at any time in favour of another management option.

Security: measures to ensure the prevention of malicious actions (theft, sabotage, illegal transfer, etc.) involving nuclear materials, other radioactive substances or associated facilities, to detect these acts and respond to them

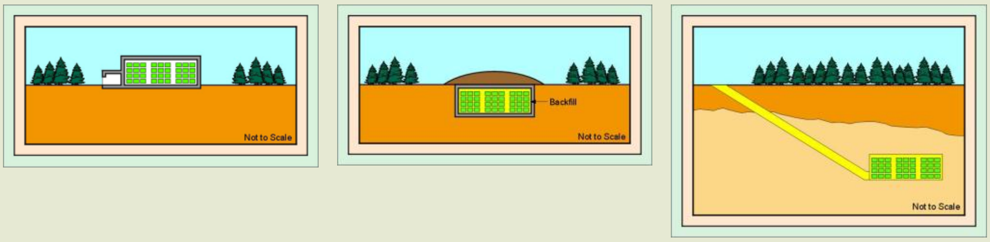


Figure 21 – Different types of eternal storage facilities (surface, near-surface or deeper) (source: [91]).

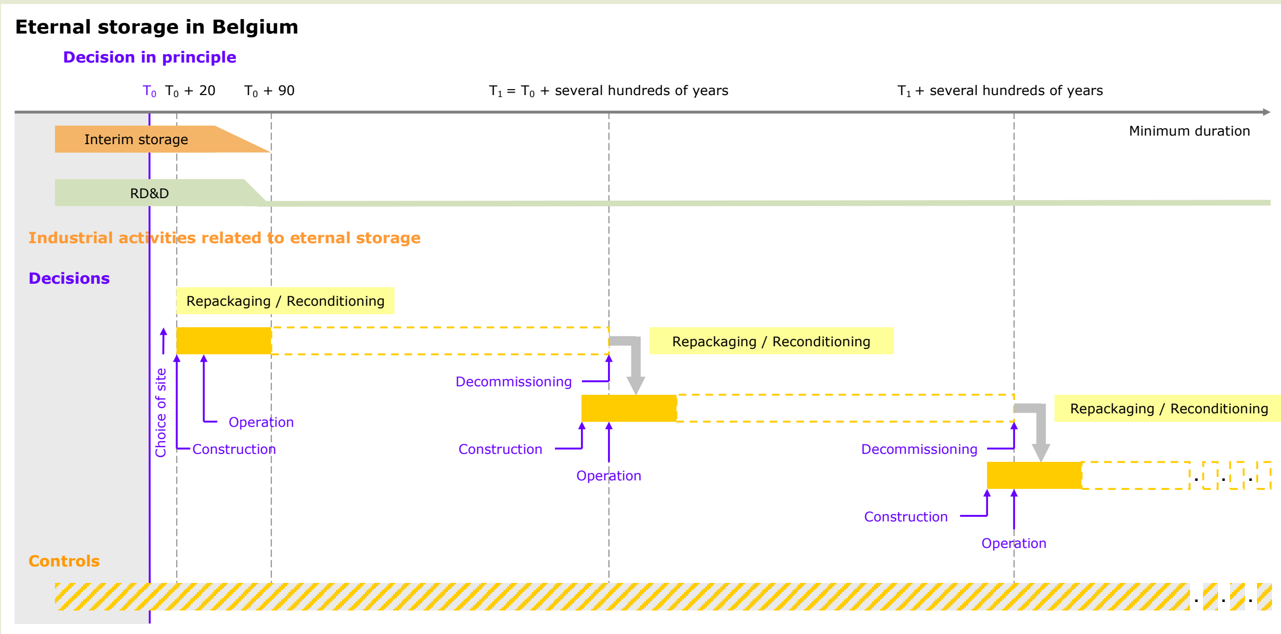


Figure 22 – Possible succession of industrial operations considered in the case of eternal storage. The indicative schedule is based on the assumption that these operations take place normally and that the necessary licences are granted.

6.1.2 Passive safety management options

Two passive safety management options that can become definitive can reasonably be considered: geological disposal and deep borehole disposal. Other passive safety management options that can become definitive which have been previously considered in varying degrees of detail internationally must be ruled out straight away (Inset 11).

Geological disposal (see SEA, section 7.2.1.2) consists in placing conditioned radioactive waste, enclosed in one or several artificial barriers, more correctly known as "engineered" barriers, in a specially designed facility, constructed in a suitable geological host formation (Figure 23). Once all the waste has been disposed of, the repository can be closed, if necessary after an *in situ* observation period. After closure, the safety of man and the environment is ensured by the system comprised of the engineered barriers and the geological formation, that together confine the waste and isolate it from the surface environment. The relative importance of the role of the engineered barriers and the natural barrier in the safety of the geological repository depends on the nature of the natural barrier. When the natural barrier (particularly, clay and salt) plays the key role, it takes over from the engineered barriers as these degrade, significantly retaining radionuclides and chemical contaminants released by the waste and the engineered barriers and consequently delaying their migration to the surface environment. The host formation must then have appropriate stability characteristics, have a low permeability and be and remain free of transport pathways, such as fissures, towards the surface, including in the long term. A geological repository can continue to be controlled after its closure (Figure 24).

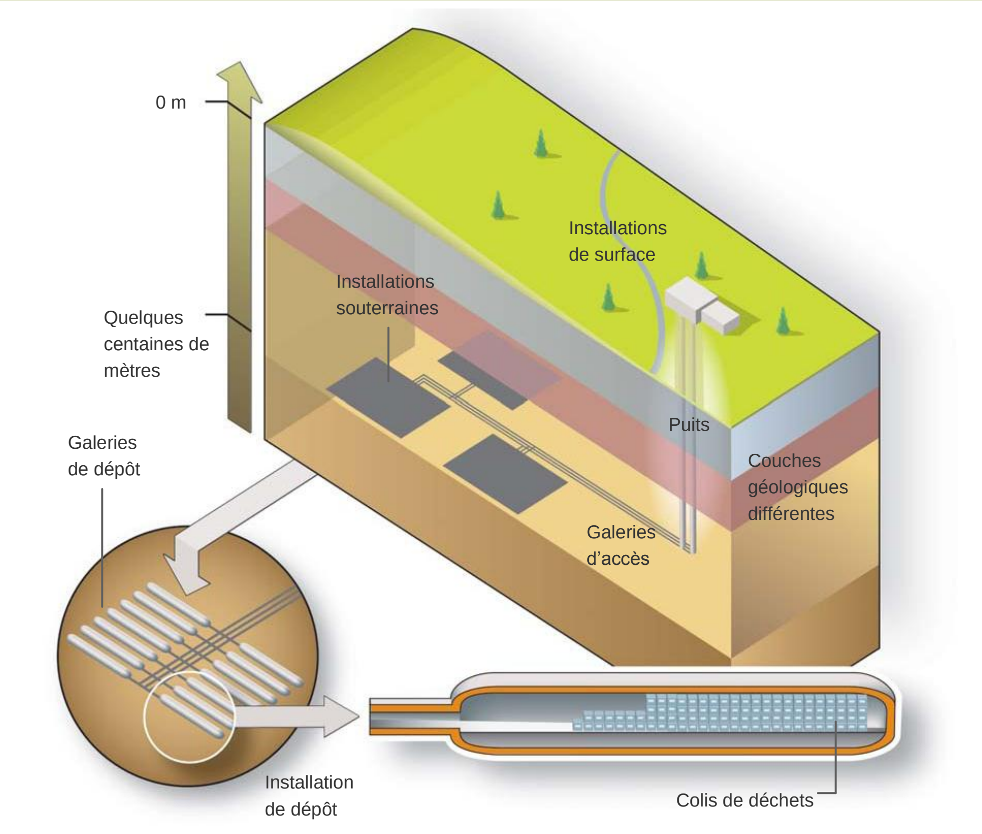


Figure 23 – Typical representation of a geological repository (adapted from [93]).

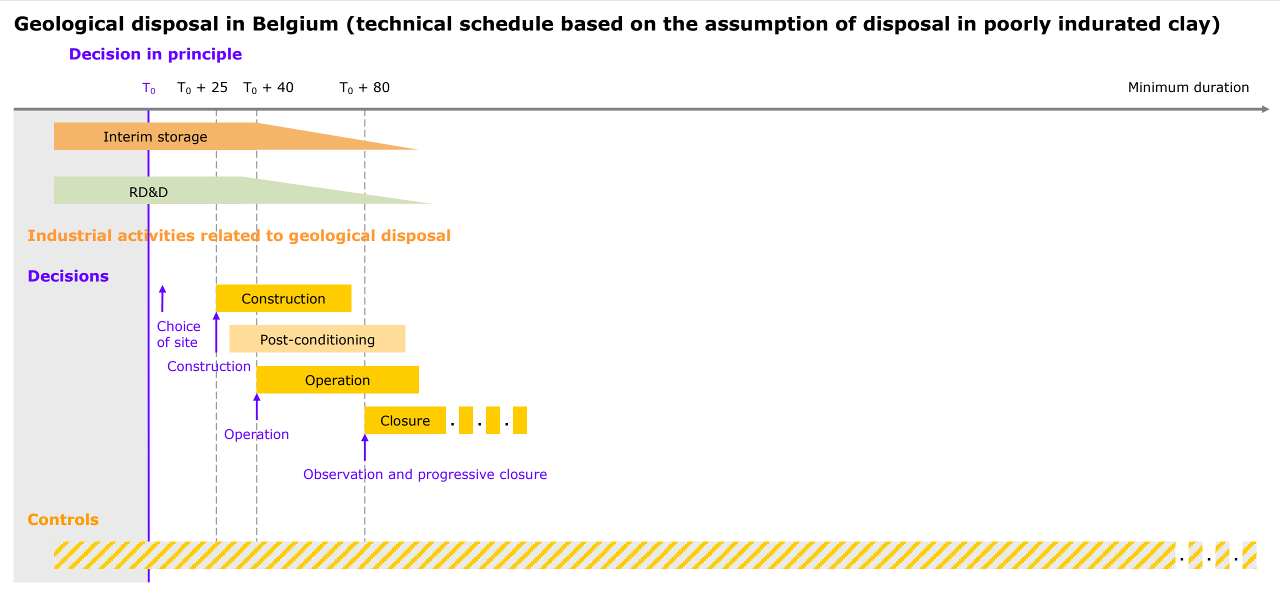


Figure 24 – Possible succession of industrial operations considered in the case of geological disposal. The indicative schedule is based on the assumption that these operations take place normally and that the necessary licences are granted.

Deep borehole disposal (see SEA, section 7.2.1.2) consists in stacking the radioactive waste containers, several metres long and 0.5 to 1 metre in diameter, in very deep (exceeding 1 000 metres) narrow boreholes over large extents (several hundreds of metres), then backfilling these boreholes, typically with a cementitious material (Figure 25). Since the containers deform under the pressure of the geological host formation, the formation is eventually the only barrier between the waste and the environment. It must therefore be free of transport pathways, such as fissures, to the surface and generally have the same characteristics as the host formations considered for geological disposal. The objective is that after complete closure of the boreholes, the system safely isolates and confines the radioactive waste in a passive way. Limited controls are still possible, but are unavoidably very indirect due to the depth of the boreholes.

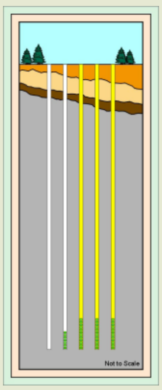


Figure 25 – Typical representation of deep borehole disposal (depth greater than one kilometre) (source: [91]).

Inset 11 – Passive safety management options described in the SEA but rejected

Various passive safety management options briefly described in the SEA but immediately rejected are mentioned here for completeness (see SEA, section 7.1). These options are in violation of international treaties or conventions to which Belgium is a signatory (**I**) and/or the Belgian legal and regulatory framework (**B**) and/or do not provide adequate safety guarantees (**S**). There is broad consensus among radioactive waste management organisations, national and foreign safety authorities, and within international organisations as to their unsuitability for the long-term management of B&C waste.

I *Sea dumping* (1) consists in dumping radioactive waste containers into the sea, where they freely sink to the seabed. At great depths (several kilometres), these containers may break up under pressure, which leads to the dispersal of their radioactive contents.

I *Sub-seabed disposal* (2) consists in burying radioactive waste containers in the sediments on the seabed. Either the containers have a form where they sink several metres into the sediment through gravity, or they are disposed of in previously drilled boreholes.

I *Disposal in ocean subduction zones* (3) consists in placing radioactive waste containers on the down-going tectonic plate in an ocean subduction zone so that they are taken into the depths of the earth's crust. This option is a variant of sea dumping and sub-seabed disposal.

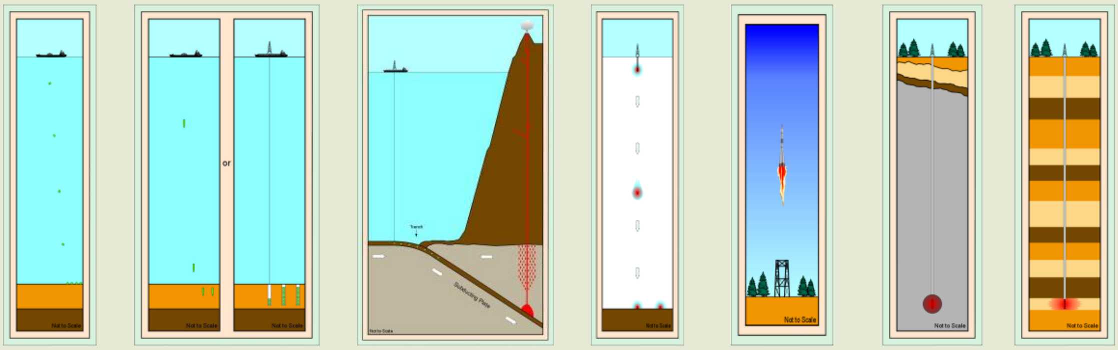
I *Ice sheet disposal* (4), which can only be considered for heat-emitting radioactive waste, consists in the gradual burying of waste containers in an ice sheet following the gradual melting of the ice caused by the heat emitted by the waste, and then the gradual formation of new ice above them.

I *Disposal in outer space* (5) consists in sending conditioned radioactive waste into space using a rocket for example, so that it is put into orbit around the earth or even leaves the earth's gravitational field.

B *Disposal by rock melting* (6), which can only be considered for radioactive waste that emits large amounts of heat, consists in either injecting the waste into a host formation in liquid or sludge form, or inserting solid conditioned waste into boreholes. In both cases, the rock that surrounds the waste liquefies under the action of the heat, which allows the waste to sink even deeper under the effect of its weight. Once the waste cools, the rock surrounding it re-solidifies, thus embedding the waste.

B *Disposal by direct injection* (7), which can only be considered for liquid radioactive waste, consists in injecting it into a deep host formation.

S *Surface disposal* consists in placing radioactive waste containers in a specially designed facility constructed on the surface or several metres below it. Such a facility typically comprises concrete modules intended to house the radioactive waste containers. These modules are isolated from rain and run-off water and/or, depending on the configuration, groundwater by a protection system of low permeability.



(1) (2) (3) (4) (5) (6) (7)

Source: [91]

6.2 Options that cannot become definitive

Two options that cannot become definitive can be considered for the long-term management of B&C waste. These options will at some point raise the issue of selecting a management option that can become definitive:

- extended interim storage, with a view towards subsequently choosing a management option that can become definitive;
- storage pending the industrial implementation of advanced nuclear technologies.

Extended interim storage (see SEA, section 7.2.2.1) consists in storing the waste in dedicated facilities for a duration ranging from 100 to 300 years, which will require future generations to decide at the end of this period on how to continue management of the waste. Extended interim storage requires the design and construction of storage facilities (surface, near-surface or deeper) that are able to protect man and the environment during this period, by means of periodic controls and maintenance and periodic verifications of the integrity of the waste containers, and repackaging or reconditioning the waste if necessary (Figure 26). The conditioning matrix and the container surrounding the waste are indeed the first confinement barriers for the radioactivity. Moreover, the site must also be controlled. During this period, the protection of man and the environment therefore relies on human actions. Consequently, in terms of management and the necessary facilities, extended interim storage is equivalent to the first step in eternal storage.

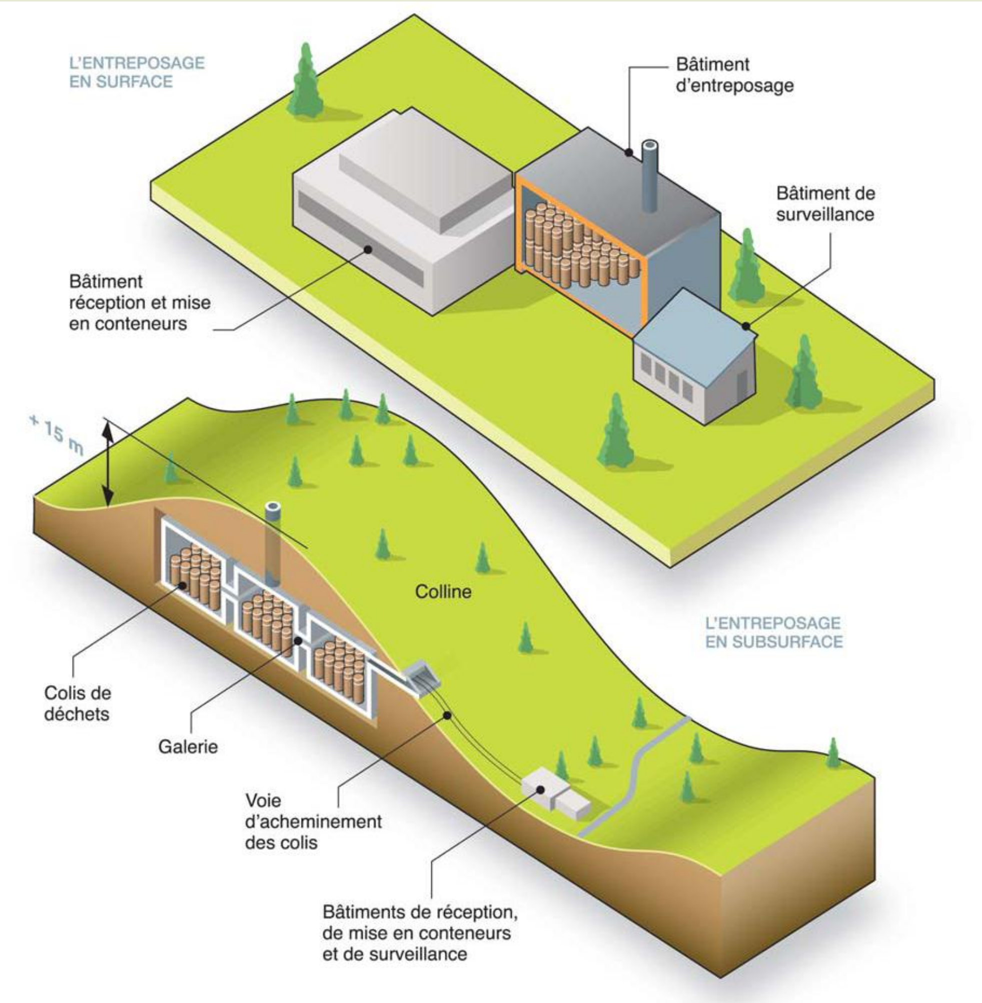


Figure 26 – Typical surface and sub-surface facilities for extended interim storage (source: [93]).

Storage *pending the industrial implementation of advanced nuclear technologies* (see SEA, section 7.2.2.2), which will at some point raise the issue of choosing a management option that can become definitive, means the extension for at least several decades of the current temporary storage situation of the waste (or at least of irradiated fuel) and/or the construction of dedicated new facilities. The advanced technologies, currently in research and development, aim in particular at more efficient use of natural resources (uranium ore) for electricity production. These technologies should also enable a reduction in the volume and danger of future high-level and/or long-lived waste. This research and development is mainly performed as part of the development of advanced nuclear reactors (4th generation reactors), in other words, within the scope of energy production, which is much broader than that of radioactive waste management. The use of advanced nuclear technologies inevitably leads to the use of advanced reprocessing for irradiated fuel.

6.3 Status quo option (or zero option)

The *status quo* option (see SEA, section 7.2.3), or zero option, which consists in opting to *decide nothing now* regarding the long-term management of B&C waste, means deferring any decision on this subject until an undetermined date and therefore leads to the extension of the current temporary storage situation (Figure 27). This extension means continuing current active management activities: periodic verifications of the integrity of waste containers, potential repackaging or reconditioning of waste, periodic maintenance of storage facilities and control of the facilities and site. Such an extension is only possible for a limited time that is determined by the state of the current storage buildings, the rate at which they are filled and the provisions of the licences. Beyond this period, the question then arises of constructing new storage facilities or choosing a management option that can become definitive.

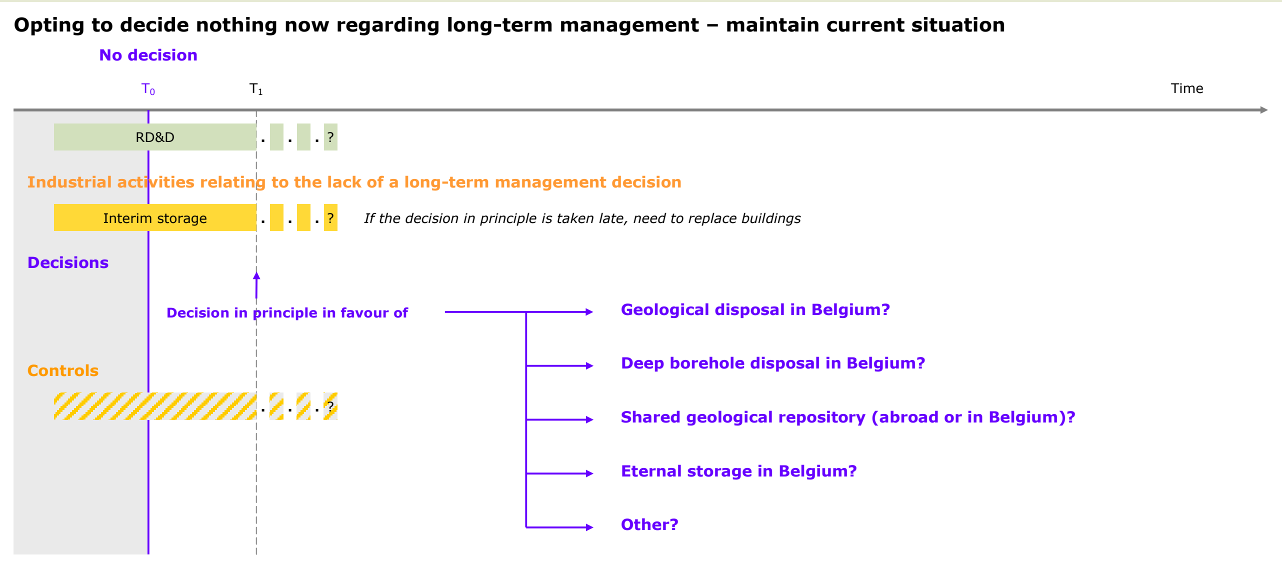


Figure 27 – Sooner or later the status quo option raises the issue of choosing a management option that can become definitive.

7 Assessing and comparing options

According to ONDRAF/NIRAS, the strategic assessment within the scope of the SEA of the management options considered in the Waste Plan for the long-term management of B&C waste reinforces the direction followed for over 30 years in Belgium in this area, namely geological disposal in poorly indurated clay (Boom Clay or Ypresian Clays). This position is presented below in stages, after an outline of the principal characteristics of the assessment methodology used in the SEA. It applies to the management of existing and planned (mainly within the scope of the *current* nuclear power programme) B&C waste, but not to new types of nuclear activities or facilities.

7.1 Assessment methodology used in the SEA

In accordance with the Law of 13 February 2006 [12] and the request by the supervisory authority of ONDRAF/NIRAS in 2004 [11], the SEA had to explore the reasonable alternatives to the solution recommended by ONDRAF/NIRAS for the long-term management of B&C waste, which is based on the implementation of geological disposal. This also comprises a brief description of the solutions that could not reasonably be retained, including the main reasons for their rejection (see SEA, section 7.1).

> The SEA *"identifies, describes and assesses the likely notable effects of implementing the plan or programme, as well as reasonable alternative solutions, taking into account the objectives and geographical scope of the plan or programme." (Law of 13 February 2006, annex II)* [translation ONDRAF/NIRAS]
>
> *"Such a work programme must allow the study of all possible long-term management strategies, as well as possible participative procedures, with the drafting of a Strategic Environmental Assessment likely to represent a significant step in this process. The results of such a study should allow a decision to be made with regard to the ultimate option to be considered and set the boundary conditions which the option must satisfy." (Letter from the supervisory authority of ONDRAF/NIRAS)* [translation ONDRAF/NIRAS]

In practice, six options are assessed in the SEA:

- eternal storage;
- geological disposal;
- deep borehole disposal;
- extended interim storage, with a view towards subsequently choosing a management option that can become definitive;
- storage pending the industrial implementation of advanced nuclear technologies;
- the status quo option.

All, with the exception of the status quo option, can be envisaged within an exclusively national framework or within a multinational framework. Extended interim storage with a view towards subsequently choosing a management option that can become definitive and storage pending the industrial implementation of advanced nuclear technologies may be examined jointly under extended interim storage (100 to 300 years) with a view to or awaiting "something else" (section 7.2.2.1). Indeed, they use the same types of facilities, with the same types of impact.

Although the Law of 13 February 2006 only focuses on analysing the environmental impacts of the options considered, ONDRAF/NIRAS wanted the SEA to be an *integrated* SEA, i.e. an SEA that compares all options according to the four aspects of a sustainable management solution (see also Inset 1 in section 1.2):

- *environmental and safety*, which refers in particular to the protection of man and the environment from the potential risks associated with B&C waste for as long as is necessary, and therefore especially to the need to ensure long-term radiological and non-radiological safety;
- *technical and scientific*, which refers in particular to the need for a scientifically justified approach and the concept of technical feasibility, in view of available knowledge;
- *financial and economic*, which refers in particular to the financing possibilities and mechanisms in accordance with the "polluter pays" principle and to the economic impact;
- *societal and ethical*, which refers in particular to the principles of intragenerational and intergenerational equity and the need for societal support.

As the Waste Plan aims to enable a strategic decision, excluding any consideration in terms of site choice, the option assessment exercise was mainly qualitative, relying on expert judgement based on the knowledge (entirely open) available at national and international level and, insofar as possible, on similar studies abroad and the consequent decisions, as well as on feedback from existing similar facilities in Belgium and abroad. However, quantitative analyses were carried out whenever possible and appropriate. More detailed analyses of the environmental impacts will be carried out at later stages, once the management solution has been chosen and/or when potential sites and possible variations in the chosen solution need to be compared. Due also to the absence of any consideration concerning site choice, transboundary environmental impacts were not assessed, which the SEA Advisory Committee judged to be justified (section 1.2.2). (For a description of the assessment methodology used in the SEA, see chapter 5 of the SEA.)

The environmental assessment distinguished between the short term (up to about 100 years after selecting a management solution) and the long term (several tens to hundreds of millennia) (see SEA, chapter 8). Indeed, different operational activities (construction, operation, etc.) will take place in the *short term*, for which environmental impacts can be assessed according to the standard outline of an impact study. This study was complemented by the review of additional criteria, so as to adequately cover the four aspects of a sustainable management solution. However, in the *long term*, and considering the uncertainties related in particular to evolution of society and the biosphere, there is little sense in assessing the environmental impacts in the same way. For the long term, it was mainly the radiological impact on man and the environment that was assessed, along with intergenerational equity aspects. The long-term assessment also considered impacts other than the radiological impact, for example, the thermal impact of category C waste on aquifers and the geological formation.

In particular, the SEA examined the robustness of the various options and the implementation conditions for each (see SEA, section 7.2, and [94, 95, 96]).

The robustness of the various options is the extent to which their ability to protect man and the environment is sensitive to evolutions over time, including the evolution of society (see SEA, chapter 10 and annex C).

All other things being equal, the reliability of the impact assessment of the management options considered mainly depends on the robustness of the options. The assessment of the various options therefore took into account different possible futures in addition to the "expected future" (section 8.1.4.4). These possible futures depend on the type of option and the timescale considered and can be classified into three groups:

- *natural evolutions*: climate warming, earthquake, severe glaciation, flood, tornado, etc.;
- *changes in the intrinsic physical and technical stability of the management facility*: premature failure of an engineered barrier, appearance of preferential migration pathways for radionuclides and chemical contaminants, etc.;
- *man-made external events*: explosion near a surface management facility, airplane crash into a surface management facility, drilling through a deep repository, etc.

In addition to the robustness of the management options in relation to different possible futures, the assessments made within the scope of the SEA also considered their robustness against different types of societal evolution: in the short term, in particular the continuation of current socio-cultural and politico-institutional trends and societal chaos, and in the long term, population migration due to rising sea levels leading to disappearance of part of the Belgian territory, a collapse in the existing system with a general regression of society, or the development of a high-technology and innovative society characterised by a stable societal structure.

The integrated SEA also provided, for each option, a response to the main issues and concerns expressed during the ONDRAF/NIRAS dialogues and the interdisciplinary conference organised to improve the SEA and the Waste Plan (see SEA, annex A).

7.2 ONDRAF/NIRAS global integrated assessment

For ONDRAF/NIRAS, the choice of the type of solution to be implemented for the long-term management of B&C waste can be narrowed down to two strategic options (Figure 29): disposal of waste in an appropriate geological formation or its extended interim storage (section 7.2.2). Indeed, of the six options assessed in the SEA, according to ONDRAF/NIRAS three have to be discarded for the long-term management of B&C waste (Figure 28 and section 7.2.1):

- the status quo option,
- the eternal storage option,
- the deep borehole disposal option.

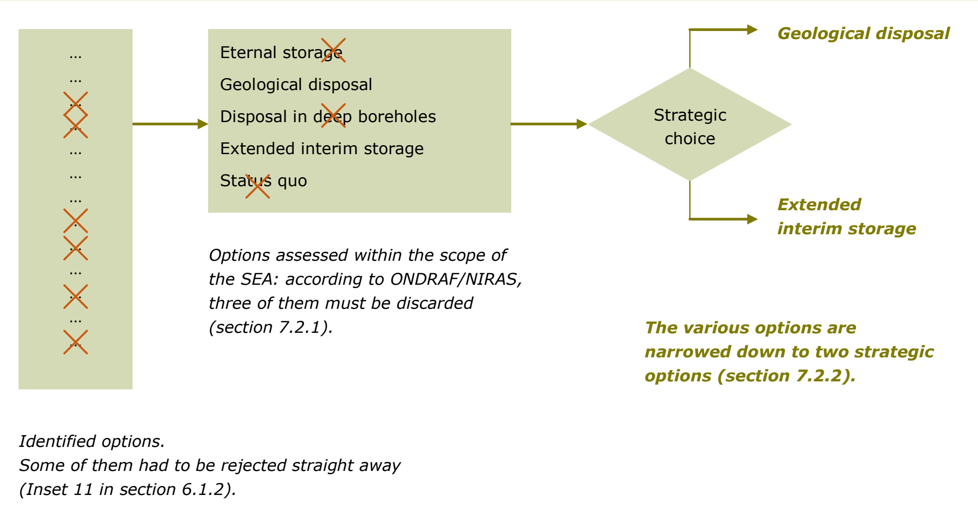


Figure 28 – Gradual process of discarding unreasonable options for the long-term management of B&C waste. This process took place in two steps: first, all options that are in violation of international treaties or conventions to which Belgium is a signatory and/or the Belgian legal and regulatory framework and/or do not provide adequate safety guarantees were discarded; second, three additional options were rejected, mainly on the basis of considerations related to safety and ethical principles.

7.2.1 The options that have to be discarded

As well as the fact that maintaining the status quo — in other words keeping B&C waste in interim storage — is by definition not a long-term management solution and does not therefore allow ONDRAF/NIRAS to fulfil its management mission, ONDRAF/NIRAS considers that eternal storage and deep borehole disposal have to be discarded for the long-term management of B&C waste in Belgium. These options were discarded for very different reasons, of which only the main ones are summarised below.

7.2.1.1 Eternal storage

Eternal storage (section 6.1.1) is essentially an abstract concept, the rationale for which does not stand up well to analysis. Indeed, eternal storage assumes repeated industrial operation cycles, each lasting from 100 to 300 years, for hundreds of millennia [94]. The safety and protection of man and the environment therefore relies to a very large extent on human actions, and does so from generation to generation. If this active management stops, the risk suddenly becomes major.

The need to provide *forever active management* of the eternal storage facilities to ensure their safety is the principal weakness of this option. Uncertainties as to how society will evolve over millennia are in fact high and, moreover, it is unrealistic to assume that knowledge for the proper management of waste can be transferred over periods that exceed imagination. Finally, it is impossible to assess the total cost of eternal storage and create a financing mechanism likely to generate the amounts needed to cover costs indefinitely. Even if the total cost could be assessed and sufficient provisions created by current generations, in accordance with the "polluter pays" principle, it is impossible to guarantee that these provisions would remain available for the purpose for which they were intended.

In addition to the fact that the safety of an eternal storage solution is highly sensitive to instabilities in society (see SEA, annex C) and natural hazards or, in other words, that such a solution is not very robust, it would transfer the responsibility for radioactive waste management from generation to generation and, as such, contravene the principle of intergenerational equity.

> *ONDRAF/NIRAS is therefore of the opinion that given the lack of robustness of any eternal storage type solution and considering that any such solution would contravene the principle of intergenerational equity, eternal storage is not an acceptable solution for the long-term management of B&C waste.*

7.2.1.2 Deep borehole disposal

The technique of deep borehole disposal (section 6.1.2) was considered and tested as early as the 1980s for the disposal of high-level and/or long-lived waste in different types of host formations (see for example [97] for salt, [98] for crystalline rocks and [99] for clays). In the 1990s, the IAEA developed a concept of deep borehole disposal (BOSS — Borehole disposal of disused Sealed Sources) to provide a solution for countries which, unlike Belgium, only have to manage very small amounts of waste in the long term, in particular disused sealed radioactive sources, notably used in radiotherapy [100]. The implementation of this concept was started in 2008 in Ghana under the auspices of the IAEA for boreholes of several hundred metres deep [100].

The main interest in (very) deep boreholes (2 to 4 km deep) is the absence or drastic limitation in groundwater movements at these depths, leading to extremely long transport times for the radionuclides to the biosphere. In view of the difficulties in characterising the geological environment at these depths, a considerable RD&D programme (estimated in 2007 in the Swedish case at over 30 years and a cost of over EUR 400 million [101]) would be needed to demonstrate the safety of deep borehole disposal.

However, in practice deep boreholes are single-barrier systems, since waste containers will very rapidly deform under the severe pressures to which they will be subjected. This technique does not therefore rely on the approach based on the use of multiple barriers, which is requested both nationally and internationally.

Although it has been subject to many studies and is periodically reassessed [98], deep borehole disposal is currently only applied in a very limited way and is only considered for small amounts of particular category B waste. Very recently, the benefits of this technique for the direct disposal of plutonium, since it reduces proliferation risks by making its retrieval difficult, or for highly toxic waste, were mentioned in two American studies. These two studies also indicate that deep borehole disposal is limited to low volumes of waste and requires additional safety studies in view of the lack of experience in this field [79, 102].

In light of current projects, notably in the oil and geothermal fields, deep borehole disposal seems feasible. These projects also show that reversibility during operation can be guaranteed, at least for boreholes several hundred metres deep. The retrieval of waste is however significantly more difficult to envisage due to the plugs that are placed every 3 to 5 waste containers in order to isolate and mechanically disconnect the successive stacks.

The deep borehole disposal option is difficult to envisage in the context of the long-term management of Belgian waste, mainly for the following reasons.

- The volumes and types of waste to be managed in Belgium do not fall within the cases traditionally considered for deep borehole disposal.
- Given the need to work at great depths and the characteristics of the Belgian subsoil, the only potentially appropriate rocks for the implementation of deep boreholes are schistose or crystalline formations. In practice, only the former can be considered, since the crystalline formations supposedly present at great depths under the Brabant Massif have never been encountered through drilling (section 7.2.2.2).

  The difficulties related to the use of schists as host formations for a geological repository (section 7.2.2.2) are therefore applicable to deep borehole disposal within these formations. Furthermore, it is difficult to make an adequate prediction about the characteristics of the rock around a borehole through just surface or drilling characterisation techniques (i.e. without using an *in situ* characterisation facility or an underground laboratory), specially given the significant depths being considered here. This difficulty is corroborated by the investigations at great depths of the European subsoil conducted for scientific purposes [96].

Finally, the dispersion and multiplicity of boreholes raises new regulatory issues: should, for example, each borehole be considered as a nuclear facility?

> *ONDRAF/NIRAS is therefore of the opinion that since the implementation of deep borehole disposal is necessarily accompanied by the difficulties specific to the schistose formations (section 7.2.2.2), would require a dedicated RD&D programme, is only practised for low quantities of waste, and does not allow the retrieval of the waste, deep borehole disposal in Belgium is not a solution that can be reasonably considered for the long-term management of B&C waste. However, it seems advisable to follow up the development of international knowledge relating to deep boreholes, which ONDRAF/NIRAS has done within the scope of the SEA and will continue to do [96] in order, should the need arise, to have a solution for the long-term management of*

very limited amounts of waste, the retrieval of which one would like to make particularly difficult.

7.2.2 The strategic choice

According to ONDRAF/NIRAS, the fundamental choice to be made with regard to the type of solution to be implemented for the long-term management of B&C waste comes down to a strategic choice between two possibilities (Figure 29):

- disposal in an appropriate geological formation
- or extended interim storage.

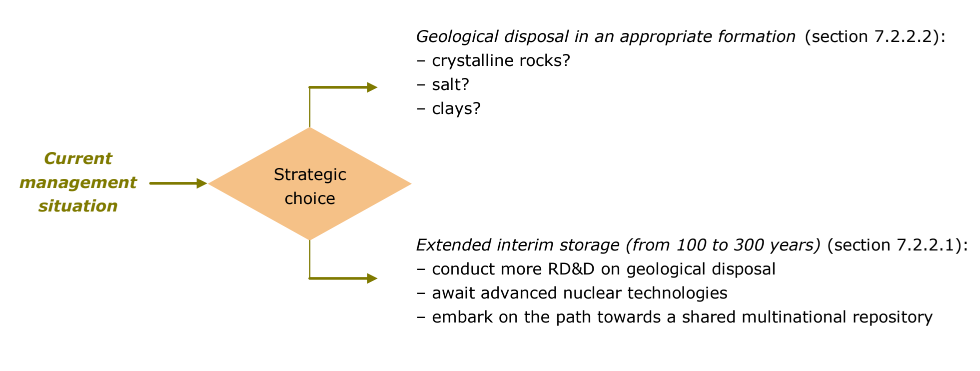


Figure 29 – The choice to be made in terms of the long-term management of B&C waste is a strategic one between geological disposal and extended interim storage.

The strategic choice to be made in terms of the long-term management of B&C waste is comparable to that required of the Government in 1997 concerning the long-term management of category A waste. At the time, ONDRAF/NIRAS requested that the Government make a strategic choice between the final disposal of this waste or an extended interim storage (over 100 years). This request was based on a comparison, particularly from a safety and environmental perspective, of the various possible options for the long-term management of category A waste [61]. A choice in favour of final disposal would have eventually led to the question of the type of final disposal (surface or deep) to be implemented. A choice in favour of extended interim storage would have led, several generations later, to the recurrence of the issue of the long-term management solution to be implemented.

The request made to the Government in 1997 was followed by a decision shortly afterwards in early 1998 when the Council of Ministers opted for *"a solution that is definitive, or can become definitive, and is progressive, flexible and reversible"* [translation ONDRAF/NIRAS] for the long-term management of category A waste, in other words a *final disposal* type solution. Since then, the category A project has developed in stages (section 4.2.3).

The preference given to the disposal of category A waste rather than its extended interim storage was recalled some years later, along with its justification, in the preamble of the Law of 2 August 2002, agreeing to the Joint Convention [7]:

> *"the solution to dispose of low-level and short-lived waste was preferable to extended interim storage because the latter did not present sufficient guarantees for the protection of future generations."* [translation ONDRAF/NIRAS]

A similar type of question is now posed for the long-term management of B&C waste.

The major difference between geological disposal and storage for 100 to 300 years is the fact that storage is not a management solution that can become definitive, contrary to geological disposal, which can also become a system that ensures passive safety after complete closure. However, the operational period (construction, operation, closure) of a geological disposal facility (of the order of about 100 years) requires active management and is in this respect similar to the operational period of a storage facility.

Although geological disposal benefits from significant institutional support at international level (Inset 12) and is the solution that has been chosen by OECD countries with one or several commercial nuclear power plants that have defined a policy for the long-term management of their high-level and/or long-lived waste (Inset 10 at the end of section 5.2.3), ONDRAF/NIRAS compared the advantages and disadvantages of geological disposal with those of storage for 100 to 300 years (Table 5 and Table 6). This comparison was made based on those criteria that seemed most relevant in differentiating between the long-term management options. They focus on the four aspects of a sustainable solution for this management.

Inset 12 – Examples from institutional support at international level and international recommendations for the geological disposal of high-level and/or long-lived conditioned waste

- Action 21 Programme *A Blueprint for Sustainable Development* by the United Nations, 1992 [25]

  "22.8. States, in cooperation with international organizations, where appropriate, should: a) Promote research and development of methods for the safe and environmentally sound treatment, processing and disposal, including deep geological disposal, of high-level radioactive waste; b) Conduct research and assessment programmes concerned with evaluating the health and environmental impact of radioactive waste disposal. […]"

- *Sixth Situation Report from the Commission to the European Parliament and the Council on Radioactive Waste and Spent Fuel Management in the European Union* (8 September 2008), intended to restart the debate on European Union legislation on the subject [103]

  "Following 30 years of research, it is sufficiently demonstrated that geological disposal now represents the safest and most sustainable option for the long term management of high level waste and spent fuel subject to direct disposal, even though implementation-oriented research and development needs to continue in those subject areas identified by the principal research stakeholder organisations and coordinated through the 7th Euratom Framework Programme."

  "It is the Commission's view that many scientific and technical areas important to geological disposal have reached maturity level, and moving towards implementation should be encouraged and facilitated."

- Resolution 1588 *Radioactive waste and protection of the environment* from the Parliamentary Assembly of the Council of Europe (PACE), adopted on 23 November 2007 by the Standing Committee on behalf of the Assembly [104]

  "11. It calls on the Council of Europe member and observer states confronted with the issue of nuclear waste management to: 11.1. encourage geological tests to identify suitable sites (which ensure long-term stability and

which allow the use of multiple barriers to prevent radionuclides from reaching the ground surface) for the building of deep geological repositories for radioactive waste, this being the solution currently considered the most appropriate in order to ensure the long-term preservation of the environment, and, if such sites are identified, to proceed with the building of such repositories;"

- Collective statement by the NEA Radioactive Waste Management Committee (RWMC) *Moving Forward with Geological Disposal of Radioactive Waste*, 2008 [105]

  "A geological disposal system provides a unique level and duration of protection for high-activity, long-lived radioactive waste. The concept takes advantage of the capabilities of both the local geology and the engineered materials to fulfil specific safety functions in complementary fashion, providing multiple and diverse barrier roles."

  "The overwhelming scientific consensus worldwide is that geological disposal is technically feasible. This is supported by the extensive experimental data accumulated for different geological formations and engineered materials from surface investigations, underground research facilities and demonstration equipment and facilities; by the current state of the art in modelling techniques; by the experience in operating underground repositories for other classes of waste; and by the advances in best practice for performing safety assessments of potential disposal systems."

  "Disposal can be accommodated in a broad range of geological settings, as long as these settings are carefully selected and matched with appropriate facility design and configuration and engineered barriers."

- IAEA publication *Policies and Strategies for Radioactive Waste Management*, 2009 [74]

  "Disposal in deep geological repositories is generally considered to be the best way to provide a permanent management solution for spent fuel and HLW."

- Article *Long-Term Management of High-Level Waste: Defining National Strategies as a Sound Application of the Precautionary Principle* by EDRAM, an international association that brings together eleven national radioactive waste management agencies, 2009 [76]

  "Disposal in a stable geological host formation in a facility designed to be intrinsically safe, which has been under investigation for decades now in many countries, is generally considered within the international scientific community as a solution that is technically feasible. Provided that geological settings are carefully selected and matched with appropriate facility design and engineered barrier system, it can ensure long-term safety, while being a priori definitive, hence avoiding to shift heavy technical burdens on to future generations […]. This position is supported by the massive amount of knowledge and understanding around geological disposal available worldwide."

For other examples drawn from institutional support, see also [106, 107].

The comparison between geological disposal and storage lasting 100 to 300 years highlights two aspects which, according to ONDRAF/NIRAS, decisively favour geological disposal as a solution for the long-term management of B&C waste.

- The *robustness* of geological disposal with respect to future evolutions (societal, natural, etc.), i.e. the fact that the safety of a repository system appropriately designed and implemented is not unacceptably affected by future evolutions. On the other hand, the safety of storage requires active management and is, therefore, particularly dependent on societal evolutions: safety might no longer be ensured if active management is disrupted.
- The fact that geological disposal passes *minimum burdens* on to future generations. By contrast, any storage solution *de facto* transfers the whole management responsibility, including considerable burdens, to future generations, which will have to decide on a solution that can become definitive, or on a new storage period at the end of the extended interim storage period.

Table 5 – Cross-disciplinary assessment of the "extended interim storage" management option for B&C waste.

Criteria	Extended interim storage
Definitive character (in connection with the possibility of retrieving the waste)	Essentially, waste storage cannot become definitive: the lifetime of an extended interim storage facility may last from 100 to 300 years through regular maintenance and replacement of equipment and is largely determined by the durability of the concrete structure. Therefore, sooner or later the issue of a management solution to replace it will arise. The stored waste can be retrieved at any time.
Safety – in the short term (< 100 years) operational radiological controllability (direct/indirect) – in the long term (>> 100 years) operational radiological controllability (direct/indirect)	The operational and radiological safety of a storage facility can be ensured. However, radiological safety can only be ensured through active management of the facility (controls and maintenance). Such facilities exist, both in Belgium and abroad. A storage facility can and must be controlled throughout its entire operation. This control can be direct (control of the waste containers) and indirect (control of the facility, site and areas surrounding the site). If needed, the waste can be retrieved from the facility. The safety of a storage facility at the end of its life (*a priori* up to 300 years) depends on the management actions taken at this time (transfer of waste to another storage facility, dismantling of the storage facility, etc.).
Robustness with regard to – natural evolutions – evolutions in the intrinsic physical and technical stability of the solution – man-made external events – evolutions in society	The design of the facility, the choice of the site and the conditioning of the waste can be implemented in such a way as to make an extended interim storage solution robust against natural evolution (earthquakes, floods, etc.), evolution in the intrinsic technical and physical stability of the facility, and man-made external events. However, the robustness of an extended interim storage solution with regard to evolution of society is weak: disruptions in its active management may lead to unacceptable consequences for man and the environment. Over a period of 100 to 300 years, the risk of disruptions in society is judged to be relatively limited.
Feasibility – existence of suitable sites for facilities – existence of suitable technologies	There are many possible sites for facilities that satisfy the necessary requirements (mechanical stability, low risk of flooding, etc.) for storage facilities. There are already storage buildings with a lifespan of approximately 75 to 100 years. According to foreign studies, it would be possible, through research and development into construction techniques, to extend the lifespan of storage buildings to approximately 300 years. However, the storage of irradiated fuel assemblies for several centuries raises the issue of their behaviour over such periods (mechanical stability, corrosion, etc.).

(continued on the following double page)

Table 6 – Cross-disciplinary assessment of the "geological disposal" management option for B&C waste.

Criteria	Geological disposal
Definitive character (in connection with the possibility of retrieving the waste)	Geological disposal is a management solution that can become definitive (step-by-step closure of the repository to make it a management system ensuring safety in a passive way, with a definitive character related to the stability of the geology of around one million years). The degree of retrievability of the waste reduces as the repository is closed and the cost of retrievability increases as a result. Once the repository is completely closed, the retrieval of the waste is similar to a mining out operation (operation to re-open the closed repository).
Safety – in the short term (< 100 years) operational radiological controllability (direct/indirect) – in the long term (>> 100 years) operational radiological controllability (direct/indirect)	During its operation, a geological repository is a nuclear facility where activities similar to those taking place in storage facilities are performed (emplacement of waste), but with additional aspects due to its underground nature (lifts, ventilation, fire protection, evacuation, etc.). Direct (around the waste) and indirect (around the facility) controls of the repository behaviour are possible and necessary. There is a geological disposal facility for long-lived waste in operation in the United States (WIPP repository, built in a salt formation). As the repository is closed, the system changes from an active system to a passive one. After closure, radiological safety is provided by the disposal system itself (i.e. by the system formed by the engineered barriers and the natural barrier), as demonstrated by the many safety studies conducted in many countries, and no longer requires human intervention. This does not prevent controls (indirect) being carried out.
Robustness with regard to – natural evolutions – evolutions in the intrinsic physical and technical stability of the solution – man-made external events – evolutions in society	Due to the disposal system design, a geological disposal solution is very robust with regard to natural evolution, evolution in the intrinsic physical and technical stability of the system, and man-made external events. The choice of a suitable host formation and site plays an important role in terms of placing waste in a stable environment, beyond the reach of natural perturbations or evolutions. The engineered barriers and the host formation are chosen so as to form, with the conditioned waste, a system which is as stable as possible, which contributes to the intrinsic robustness of the disposal system. Furthermore, a geological repository is very robust with respect to societal evolutions because it is not necessary to ensure active management of the repository after its closure. If institutional memory of the location of the repository is lost, the risk of human intrusion cannot be excluded.
Feasibility – existence of suitable sites for facilities – existence of suitable technologies	Potential sites for a geological repository are limited to those where there is a potential geological layer. Internationally, it is primarily crystalline rocks, salt and clays which are studied as potential host formations for a repository. In Belgium, large areas where poorly indurated clays (Boom Clay or Ypresian Clays) are present are promising. The possibility of excavating galleries by industrial methods in poorly indurated clay has been proven. The technologies necessary for the disposal (excavation and construction of underground galleries, technologies relating to the fabrication and emplacement of containers, etc.) are sufficiently developed and proven to allow, in several countries (particularly Finland and Sweden), the practical implementation of a repository to begin. There is a geological disposal facility in the United States: the WIPP.

(continued on the following double page)

Criteria	Extended interim storage
Environmental impact (see also SEA, chapter 9) – in the short term (< 100 years) radiological impact chemical impact physical perturbations (noise, etc.) site area – in the long term (>> 100 years) radiological impact chemical impact physical perturbations (noise, etc.)	In the short term, the expected radiological and physicochemical effects during waste storage are largely lower than the legal limits. This statement is supported by the feedback associated with storage facilities in many countries. The expected physical perturbations are the effects traditionally associated with a construction site. A limited number (< 10) of storage facilities have a total site area of several tens of hectares, enough for the management of all B&C waste. At the end of an extended interim storage facility's life, a new decision on long-term management and a series of actions are needed, leading to radiological exposure of future workers and dismantling activities. The long-term impact depends entirely on this new (future) decision.
Ethical aspects – transfer of burdens on to future generations – maintain freedom of choice (adaptability, reversibility, retrievability) (sections 9.1.3 and 8.1.3)	An extended interim storage solution transfers significant burdens (technical, financial, radiological, decision-making, etc.) on to future generations, and in particular the responsibility of implementing a management solution that can become definitive. It also requires knowledge transfer from generation to generation. An extended interim storage solution does however allow much freedom of choice for future generations, including the choice to retrieve the waste if they wish.
Flexibility – with regard to the types of waste – with regard to the waste volumes – with regard to a possible extension of the operational period of the power plants	Different types of waste can be stored in different storage buildings, as is already currently the case, with buildings designed (for example the wall thickness) depending on the danger of the waste. Storage capacities can be increased as needed, by extending existing buildings or constructing new ones. A potential extension of the operational period of existing nuclear power plants only has a limited impact on the necessary storage capacity (Table 7 in section 10.2.2). There is flexibility with regard to the location for implementing extended interim storage.
Safeguards / security	Existing techniques and measures of security and safeguards (i.e. surveillance of the site and facilities and control and inspection of the site and facilities containing fissile materials) currently applied internationally (IAEA and Euratom) for the interim storage of radioactive waste, including irradiated fuel, remain in effect.
Cost – possibility of calculating – possibility of establishing a financing mechanism	The cost of storage facilities can be calculated. However, since storage is not a management solution that can become definitive, the cost as calculated does not cover the cost for a solution that can become definitive and therefore only represents a fraction of the total management cost. An extended interim storage solution can be financed by the existing mechanism of the long-term fund, but with significant uncertainty in terms of covering costs for the solution that can become definitive to be implemented after storage.

Criteria	Geological disposal
Environmental impact	
(see also SEA, chapter 9) – in the short term (< 100 years) radiological impact chemical impact physical perturbations (noise, etc.) site area – in the long term (>> 100 years) radiological impact chemical impact physical perturbations (noise, etc.)	In the short term, the expected radiological and physicochemical effects of a geological disposal facility are largely lower than the legal limits. The expected physical perturbations are the effects traditionally associated with a construction site, the excavation and operation of an underground facility over a period of several decades and the operation of surface facilities, such as post-conditioning facilities (section 8.1.2). The site area would be approximately 75 hectares. In the long term, all the studies, in Belgium and abroad, show that a well-designed and implemented geological disposal system is such that the expected radiological and physicochemical effects are lower than the legal limits. The long-term radiological impact (over tens of millennia) on the repository's direct environment will more than likely be much less than the level of natural radioactivity in the environment.
Ethical aspects	
– transfer of burdens on to future generations – maintain freedom of choice (adaptability, reversibility, retrievability) (sections 9.1.3 and 8.1.3)	A decision in principle in favour of geological disposal makes it possible to limit the burdens (technical, financial, radiological, decision-making, etc.) transferred to future generations. After the repository is closed, management activities are reduced and limited to the environmental control of the repository and knowledge transfer activities from generation to generation. The disposal system can ensure safety even if these activities are stopped. The intention is nevertheless to continue to transfer knowledge and especially to maintain institutional memory of the repository for as long as it is judged necessary. The degree of retrievability of the waste reduces as the repository is closed and the retrievability cost increases as a result.
Flexibility	
– with regard to the types of waste – with regard to the waste volumes – with regard to a possible extension of the operational period of the power plants	Until now, studies have shown no prohibitive defect in the geological disposal of the various types of existing and planned B&C waste. A geological disposal facility can be designed and operated so that wastes with different characteristics are placed in different parts of the repository, potentially sequentially. The surface area for a geological disposal facility is very limited (several tens of hectares) with regard to the lateral continuity presented by several potential geological formations present in Belgium, which makes it possible to increase its capacity according to needs. A single repository is enough for all B&C waste produced in Belgium within the scope of the current nuclear power programme and in the event that the operation of the existing nuclear power plants is extended.
Safeguards / security	
	Security controls are possible using standard techniques. The safeguards to be applied to a repository are currently being developed within a framework of international collaboration and implementation (IAEA and Euratom). The fact that the waste is placed at depth strengthens the safeguards and security aspects, even more so after the facility is closed.
Cost	
– possibility of calculating – possibility of establishing a financing mechanism	The cost of geological disposal can be calculated. Since geological disposal is a solution that can become definitive, in principle, the calculated cost represents the total cost of long-term management (taking into account potential requirements, for example in terms of retrievability, controllability and knowledge transfer). A geological disposal solution can be financed by the existing mechanism of the long-term fund.

Of course, the assessment of the respective benefits and disadvantages of the two management solutions is partly subjective, related to the weight attributed to the different principles or values taken into account. Thus, according to the observations made in Belgium and abroad, the use of the principle of intergenerational equity regarding the long-term management of B&C waste systematically leads to conflicting conclusions. The desire not to pass on undue burdens (technical, financial, radiological and decision-making) to future generations, and therefore to implement a management solution that would satisfy this requirement, has to be balanced against the desire to allow them the maximum freedom of choice with regard to the management of the waste that they receive as a legacy. After multidisciplinary thinking, the Swedish National Council for Nuclear Waste (KASAM), which advises the Swedish Government independently on the matter, concluded, on the one hand, that it would be the responsibility of the current generation to ensure the safe management of existing and planned waste, and, on the other hand, that *"A final repository should be constructed so that it makes inspection and controls unnecessary, without making inspection and controls impossible. In other words, our generation should place the entire responsibility for the final repository on future generations, but neither should we deprive future generations of the option of assuming responsibility."* [101, 108]. ONDRAF/NIRAS supports this position.

Moreover, it is impossible — and this is true in all countries where the question is asked — to settle the debate between proponents and opponents of geological disposal using irrefutable scientific evidence. Indeed, none of the parties involved in the "disposal versus storage" debate is able to prove their position, given the uncertainties of fundamentally different nature in both cases.

- *Opponents of disposal* have doubts about the quality and reliability of the arguments in favour of disposal, or even oppose it in principle, believing that waste must be able to be controlled for a long time, even as long as it presents a risk, and must be able to be retrieved at any time. They generally advocate a storage solution in the hope that a "better" solution than disposal can be found, for example a solution that could reduce or even "neutralise" the radioactivity.
- *Proponents of disposal* rely on considerable scientific and technical knowledge and generally consider the uncertainties put forward by opponents of disposal as unlikely to call into question the validity of a disposal solution. These scientific and technical uncertainties are indeed taken into account throughout the development of a disposal system so as to make it robust. Proponents of disposal base their confidence as to the safety of the solution that they advocate on the fact that the geological formations under consideration have been stable for millions of years. However, they have serious doubts about the possibility of continuing the actions necessary to maintain the safety of storage facilities over the very long term. Finally, they are of the opinion that advanced nuclear technologies will not make it possible to "neutralise radioactivity" and will not remove the need for geological disposal (section 7.2.2.1).

According to ONDRAF/NIRAS, a geological disposal facility progressively developed, implemented and closed, if need be after a period of *in situ* controls, is the only management solution capable of protecting man and the environment in the long term against the risks associated with B&C waste, and of minimising the transfer of burdens to future generations while leaving them some freedom of choice, in particular regarding controls of the repository (nature and duration – section 8.1.3.2), closure planning, possible retrieval of waste (section 8.1.3.1) and knowledge transfer to future generations (section 8.1.3.3).

In addition to the fact that a storage solution lasting for 100 to 300 years presents significant disadvantages compared with a geological disposal solution, none of the reasons that could be given to justify the need for such storage is strictly a determining factor according to ONDRAF/NIRAS (section 7.2.2.1). As for geological disposal, and considering the geological formations present in Belgium and the knowledge available, ONDRAF/NIRAS is of the opinion that poorly indurated clays (Boom Clay and Ypresian Clays) offer the best prospects for its implementation (section 7.2.2.2).

7.2.2.1 None of the reasons that could suggest storing existing and planned B&C waste for 100 to 300 years justify postponing a decision in principle in favour of geological disposal

The reasons identified as being able to suggest postponing a decision in principle in favour of a "geological disposal" type solution and preferring to store existing and planned B&C waste for some time yet (*a priori* 100 to 300 years) are as follows:

- to give time to conduct more RD&D into geological disposal and remove or at least reduce current uncertainties and/or assess deep borehole disposal for example;
- to await the industrial implementation of advanced nuclear technologies, with the expectation that these technologies will reduce the volume and danger of waste being considered for geological disposal;
- to embark on the path towards the joint development, with other countries, of a shared geological repository.

As explained below, none of these reasons justify postponing a decision in principle in favour of geological disposal. Making such a decision now does not however preclude further RD&D in order to develop the geological disposal solution and prepare for its implementation. On the contrary, this is essential and planned (section 8.1.6). Such a decision also allows developments in relevant fields to be followed up (Figure 30), follow-up being a required part of a stepwise and adaptable decision-making process, such as the one that will accompany the development and implementation of this solution (section 9.1).

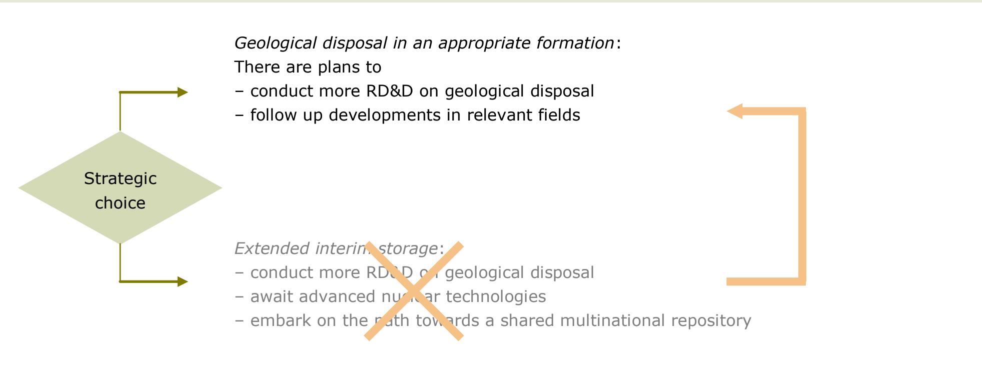


Figure 30 – Reasons that could suggest storing existing and planned B&C waste for 100 to 300 years may be taken into account as part of a decision in principle in favour of geological disposal.

In addition, in its opinion on the draft Waste Plan and the SEA, FANC confirmed the ONDRAF/NIRAS position by declaring any form of surface storage other than interim storage as is currently practised unfavourable [109].

> *"Surface disposal of high-level and/or long-lived waste (category B&C waste), whether pending the development of new techniques or for a duration of several centuries, cannot be justified for the following reasons:*
>
> - *This would represent an ongoing and long-term burden for future generations;*
> - *This solution would require maintaining the knowledge on the subject and the continued organisation of education;*
> - *The potential risk of malicious practices is higher than with other (geological) options since the materials are easily accessible on the surface;*
> - *The volume of radioactive waste would only increase due to reconditioning and would therefore require, over time, an ever larger storage capacity;*
> - *Since, in any case, a definitive solution for storing ultimate radioactive waste must be sought, deciding nothing today for this type of waste would transfer the responsibility to future generations.*
>
> *Moreover, internationally, extended interim storage (several centuries) is not considered as a reference solution for the long-term management of this type of waste."* [translation ONDRAF/NIRAS]

Conduct more RD&D on geological disposal

In the opinion of ONDRAF/NIRAS, the geological disposal solution studied in Belgium for over 30 years has achieved a sufficient level of technical maturity to be subject to a decision in principle, as explained in chapter 8. Moreover, the validity of this type of solution is the subject of broad international consensus (Inset 12 in section 7.2.2).

Postponing making a decision in principle in favour of geological disposal to conduct more RD&D beforehand would not present any decisive advantage in terms of management. Indeed, RD&D activities will continue anyway, after the decision in principle, and will focus in particular on reducing residual scientific and technical uncertainties and on confirming and refining knowledge.

> *ONDRAF/NIRAS is therefore of the opinion that there is no need to conduct more RD&D on geological disposal in order to enable the Government to make a decision in principle in favour of this solution; RD&D will of course be continued after the decision in principle.*

Await the implementation of advanced nuclear technologies

Advanced nuclear technologies are not in themselves a solution to the issue of the long-term management of B&C waste, either now or in the future (see SEA, section 7.2.2, and for example [79, 82, 102, 105, 106, 110, 111, 112]). Indeed,

- advanced nuclear technologies will not make any contribution to the long-term management of existing category B waste and existing and planned category C reprocessing waste, because this waste contains too little recoverable material for its extraction to be justified in economic, technical and safety terms;
- advanced nuclear technologies along with research in this field will themselves generate high-level and long-lived ultimate waste, which will have to be managed in the long term.

> *ONDRAF/NIRAS is therefore of the opinion that there is no need to await the industrial implementation of advanced nuclear technologies in order to decide on a long-term management solution for existing and planned (mainly within the scope of the current nuclear power programme) B&C waste.*

That said, in an electricity production context, advanced nuclear technologies aim above all for a more efficient use of fissile materials, notably by recycling actinides as much as possible (U, Pu, Am, Cm and Np). These techniques are therefore used to prevent these actinides ending up in radioactive waste produced by these advanced cycles and therefore reduce the danger of this future waste. The contribution of advanced nuclear technologies in terms of the long-term management of radioactive waste, which is currently impossible to anticipate, will, if necessary, have to be considered in this context.

It should be noted that

- it is unclear whether advanced nuclear technologies can be implemented on an industrial scale with extensive recycling of all actinides;
- the industrial implementation of these technologies would require a set of facilities which, for a country like Belgium, could only be considered at international level (mainly new nuclear power reactors, fuel fabrication facilities for these new reactors and extensive reprocessing facilities);
- the industrial implementation of these technologies involves the development and maintenance of advanced nuclear cycles (including extensive reprocessing) over long periods (about a century) before leading to a significant reduction in the danger of the radioactive waste generated;
- there is currently no accurate estimate of the types and volumes of secondary waste generated by these technologies (operational waste, dismantling waste, etc.), and it is not impossible that the generation of this new waste could reduce the interest in these technologies;
- applying these technologies to commercial irradiated fuel from the current nuclear estate, for which the management policy is unknown, could be envisaged.

> *ONDRAF/NIRAS is therefore of the opinion that although advanced nuclear technologies will make no contribution to the long-term management of existing and planned conditioned waste, it must follow up national and international developments in these technologies, since, on the one hand, the management policy for commercial irradiated fuel from the current nuclear estate is not yet known, and, on the other hand, the research*

facilities dedicated to these technologies will themselves generate waste which will have to be managed in the long term.

Embark on the path towards a shared multinational repository

According to the Joint Convention, that Belgium has ratified, each State is responsible for managing its own radioactive waste. As ONDRAF/NIRAS is able to propose a solution – geological disposal – that it considers safe and feasible for the long-term management of B&C waste (chapter 8), it is of the opinion that this waste can and should be managed in the long term on Belgian territory (see also section 8.3). Indeed, ONDRAF/NIRAS is convinced that

- future RD&D will confirm and refine current knowledge (section 8.1.6);
- it will be possible to find a suitable site in Belgium to implement a geological disposal facility (section 9.2);
- the licences (nuclear and non-nuclear) necessary to implement a geological disposal facility on Belgian territory will be obtained (section 9.2).

According to international trends, a possible management solution shared by several countries would be a geological disposal solution (see SEA, annex D). Although a shared repository could be economically beneficial for the countries in question, particularly those countries with very little radioactive waste to manage, the period needed to develop a shared repository up to its implementation would greatly exceed the period still required to reach the implementation stage for a geological repository in Belgium, particularly due to the need to develop a suitable international working framework – especially its legal aspect – and sign the necessary agreements, but also due to the likely complexity of the siting process. A particularly tricky point would be that of sharing responsibilities: Who would be responsible for existing waste disposed in the repository? Who would be responsible for the management and safety of the repository? Who would be responsible if the waste needed to be retrieved from the repository?

Finally, Belgium's participation in the development of a shared multinational repository would need to satisfy the reciprocity principle. In other words, if Belgium was part of a shared repository process, its waste would be likely to be disposed abroad just as it could be that the shared repository could be built on Belgian territory and Belgium would therefore accommodate the waste of the other countries that are party to the multinational agreement.

ONDRAF/NIRAS is therefore of the opinion that Belgian radioactive waste must be managed in Belgium and that since it is able to propose a long-term management solution that it considers is both safe and feasible, there is no need to put the waste in storage with a view to involving Belgium in a shared multinational repository process. Follow-up of developments in terms of shared multinational repositories, through international institutions, is however desirable in order to understand the policies in this area and their potential impacts on the Belgian programme.

7.2.2.2 Of the geological formations in Belgium, poorly indurated clays (Boom Clay and Ypresian Clays) offer the best prospects for disposal

To accommodate a high-level and/or long-lived radioactive waste repository, a geological formation must have several of the following characteristics [113]: it must be highly stable, be homogeneous enough to be able to be characterised with confidence, have geochemical properties that protect the engineered barriers and waste from rapid degradation, have the capacity to prevent transport of radionuclides and chemical contaminants that will ultimately be released from the waste and engineered barriers, be thick and deep enough to ensure adequate isolation of the waste, allow the construction of underground facilities, and be lacking in natural resources, the exploitation of which would be economically attractive. However, non-compliance with one of these characteristics does not necessarily lead to the exclusion of a potential host formation. It is indeed the protection offered to man and the environment, now and in the future, by the whole disposal system, i.e. the combination of waste, engineered barriers and the geological host formation, that must be considered. This is why increasing importance is given to safety analyses of the disposal system as a whole, compared to strict compliance with all favourable geological characteristics. A disposal system can thus be developed depending on its context (geological, regulatory, local societal requests, etc.).

Three main types of geological formations are usually considered for geological disposal: crystalline rocks, salt and clays (Figure 31) [89, 114, 115]. In practice, each type consists of a range of geological formations. In particular, under the term "clays", there is a continuum from poorly indurated clays, such as Boom Clay or Ypresian Clays, to indurated clays, such as the Callovo-Oxfordian Argillites chosen as a host formation in France or the Opalinus Clays selected to host a repository in Switzerland. Schists cover a great variety of sedimentary rocks that have been subject to more or less consequential mineralogical and structural transformations. Depending on the importance of these transformations, they become close to either indurated clays (while presenting a marked cleavage) or crystalline rocks. The depths considered are in the range of several hundreds of metres.

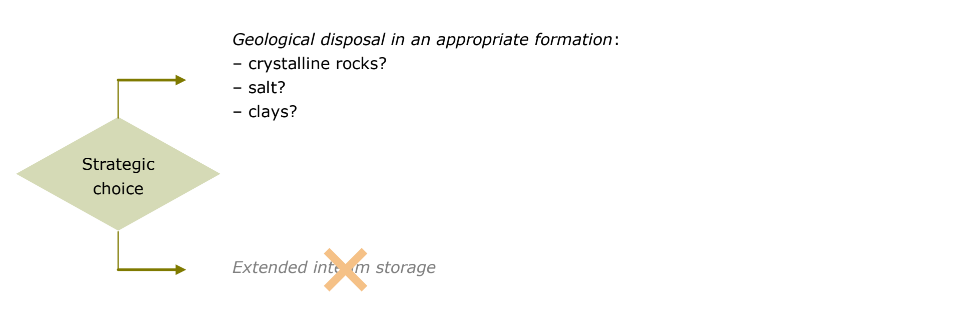


Figure 31 – Three main types of geological formations are usually considered for geological disposal: crystalline rocks, salt and clays.

Between 1976 and 1979, a study conducted under the auspices of the European Commission, based on existing bibliographic information, enabled a European catalogue of favourable formations for geological disposal to be drawn up [115]. The development of this catalogue was based on the application of geological criteria derived from international recommendations at the time, notably from the IAEA [114]. The application to Belgium of the methodology used to draw up the European catalogue led to the selection of only clay formations: those composed of schists and those composed of poorly indurated, plastic rocks, namely Boom Clay and Ypresian Clays [116]. This confirmed the preference that SCK•CEN had given several years previously to the study of poorly indurated clays, and in particular the study of Boom Clay (section 8.1.1). In Belgium, there is no equivalent to the Callovo-Oxfordian or Opalinus Clays selected in France and Switzerland respectively as host formations.

ONDRAF/NIRAS regularly re-evaluated, especially when drawing up the SEA, the relevance of the conclusions established in 1979 during the drafting of the Belgian catalogue of geological formations with favourable characteristics for disposal, considering both available data and guidance currently available on the subject (for example [113]). The primary conclusions of this re-evaluation were as follows.

Crystalline and salt formations

Crystalline and salt formations were not selected in the 1979 Belgian catalogue. This position remains valid.

- Recent investigations have made it possible to presume the presence of a large *mass of crystalline rocks* in the deep core of the Brabant Massif. Its characteristics are still largely unknown because it has never been drilled. Since it is located at a depth of over two kilometres, within a complex and very old geological structure, its detailed characterisation would be difficult and the feasibility of mining within it is uncertain [117].
- *Salt formations* are present at great depths (600 m to 3 km) in Belgium (Campine Basin and south of the Brabant Massif). These are principally intermittent intercalations within other formations, some of these intercalations being subject to dissolution phenomena. These two characteristics are prohibitive defects for a potential host formation [118].

Schistose formations

Included in the Belgian catalogue established under the auspices of the European Commission in 1979, schists (Figure 32), although potentially favourable as host formations, were discarded at the time by SCK•CEN in favour of poorly indurated clays, and in particular Boom Clay, notably because they have highly heterogeneous characteristics on Belgian territory and were largely unknown at depth. Three decades after this first study, the re-evaluation conducted by ONDRAF/NIRAS with the assistance of a panel of experts shows that these conclusions remain valid. However, they do not allow schists to be excluded *a priori* as potential host formations [119].

Schists from the metamorphism of sedimentary clay rocks do indeed have a series of properties that are assumed favourable for hosting a geological disposal facility, but also potentially unfavourable properties and/or properties that make their characterisation difficult.

Principal *assumed* favourable properties of schists:

- Schists are likely to present themselves locally at great depths and significant thicknesses while being mechanically robust, which should provide good isolation for a geological disposal facility.
- The very broad spatial distribution of schists in Belgium would make it possible to consider many potential disposal sites.
- Despite the transformations of clay minerals resulting from regional geological history, certain schists could have maintained the potential to retain (i.e. trap) radionuclides.
- The schistose geological barrier would only be slightly perturbed (for example mechanically) by the presence of a repository.

Principal unfavourable properties of schists:

- Schists cover a wide variety of sedimentary clay rocks that have been subject to more or less advanced mineral transformation during regional geological history, which has resulted in heterogeneity and large variability in these rocks.
- Schists generally appear within complex geological environments.
- Schists have many structural features (sedimentary and/or metamorphic) that could prove to be water conducting features. The presence of such structures (cleavage, fractures, etc.) could speed up the transport phenomena throughout the formation and would greatly complicate their modelling.
- The heterogeneity and variability of the schists, the presence of sedimentary and/or metamorphic structures along with their complex geological environments would make it difficult to characterise them from the surface and would affect the possibility of transferring data acquired about one location to another location with many uncertainties. Detailed characterisation would therefore require drilling many boreholes for each considered location. Furthermore, this could, to a certain extent, affect the schists' favourable properties (isolation and confinement capacities in particular).
- Even if schists that have only been subject to a slight metamorphism have probably retained a certain self-sealing capacity, this is likely to be weak or very weak.
- Many schistose formations present in Belgium are rich in coal.

Given the above, the confirmation of the favourable properties of schists as a host formation would require starting many dedicated scoping and characterisation campaigns that would be highly marred by uncertainties if they were conducted from the surface, in view of the special features of these rocks and their environment. It also appears that given the significant variabilities and the difficulties in transferring knowledge from one location to another, the most suitable way of considering schists for a geological disposal facility would be to focus on one or several sites rather than seek large-scale characterisation. Furthermore, it is worth noting that many schistose formations contain aquifers in their part close to the surface.

Additionally, no other country is currently considering formations analogous to the schists present in Belgium, with their complex geological environment, as a potential host formation for geological disposal. Consequently, the knowledge acquired from the Belgian programme with regard to geological disposal and that from foreign programmes could only be used in a very limited way if ONDRAF/NIRAS had to study schists as a potential host formation. This would inevitably lead to the development of a new concept of geological disposal, suited to the special geological features of schists (notably the presence of structures that could potentially be water conducting features). This would have significant consequences for both the development schedule for a geological disposal solution and its cost, and would be done at the expense of studies into clay, which would notably result in a loss of knowledge and continuity.

> *ONDRAF/NIRAS is therefore of the opinion that although schists could be an alternative to poorly indurated clays as a host formation for geological disposal, the prospects and potential difficulties are such that an investment in RD&D is not currently justified. ONDRAF/NIRAS will continue the assessment of schists as a host formation on the basis of existing knowledge and the (preliminary) requirements that FANC is currently developing. It also seems appropriate to follow up the development of knowledge about schistose formations on their own and as potential host formations so as to have a fallback solution in Belgium if poorly indurated clays eventually have to be rejected.*

Figure 32 – Schists outcrop in Ardennes showing the typical development of a cleavage (foliation) (source: Prof. M. Sintubin, KUL).

Poorly indurated clay formations (Boom Clay and Ypresian Clays)

According to the re-evaluation, poorly indurated clays (Boom Clay and Ypresian Clays) have very favourable properties for confining waste and retaining radionuclides and chemical contaminants, and are easier to characterise than schists. So far, poorly indurated clays have not shown any prohibitive defects as potential host formations and offer plenty of flexibility in the choice of a disposal site (see also chapter 8).

- Boom Clay was deposited 35 million years ago and is found in the subsoil in the north-east of Belgium (Campine Basin). Its thickness and depth increase towards the north-east. This clay is characterised by a simple geometry and very high lateral continuity, which facilitates its characterisation (Figure 33) [120]. It shows a high capacity for self-sealing and retaining radionuclides and chemical contaminants (section 8.1.4). Nevertheless, its plasticity requires a certain number of precautions to be taken during underground excavations (section 8.1.1).
- Ypresian Clays were deposited 55 to 49 million years ago and are found in the subsoil throughout northern Belgium (section 8.1.5). Like Boom Clay, Ypresian Clays have a simple geometry. However, they are characterised by greater heterogeneity, both lateral and vertical (Figure 33). So, while in the west of the country, Ypresian Clays have a high clay content, in Campine they are essentially sandy [121]. Ypresian Clays presenting a lithology, thickness and depth suitable for waste disposal are only located in the northernmost part of the west of the country.

A point for attention relating to poorly indurated clays in Belgium is the presence of aquifers in their immediate geological environment.

ONDRAF/NIRAS is therefore of the opinion, on the one hand, that poorly indurated clays are more likely to satisfy the requirements generally imposed internationally for host formations [114] and the (preliminary) requirements that FANC is currently developing, and, on the other hand, that continuing RD&D into Boom Clay and Ypresian Clays as potential host formations is recommended to put the encouraging knowledge from the Belgian programme to best use.

Figure 33 – Left, overview of a clay quarry (Kruibeke) showing the characteristic band structure of Boom Clay; right, overview of a clay quarry (Marke) showing the same type of band structure in Ypresian Clays, but with structural discontinuities (faults).

8 Geological disposal in poorly indurated clay (Boom Clay or Ypresian Clays) as a technical solution for long-term management recommended by ONDRAF/NIRAS

The technical solution recommended by ONDRAF/NIRAS for the long-term management of existing and planned (mainly within the scope of the current nuclear power programme) B&C waste is *geological disposal in poorly indurated clay (Boom Clay or Ypresian Clays)* (section 8.1) *in a single facility* (section 8.2) *on Belgian territory* (section 8.3) *as soon as possible,* but with the pace of development and implementation of the solution needing to be proportionate to its scientific and technical maturity, as well as its societal support (section 8.4). This solution has attained an advanced level of technical maturity, which is sufficient for it to be subject to a decision in principle. It must still however be subject to additional RD&D activities, which will gradually evolve towards confirming and refining knowledge, and preparing for the industrial phase of implementation and for the licence application files.

This technical solution is part of a decision-making process that integrates the technical and societal aspects (chapter 9). Its development and implementation have attached conditions arising from the societal consultation organised on the initiative of ONDRAF/NIRAS and from the legal consultation (section 8.1.3).

8.1 Geological disposal in poorly indurated clay (Boom Clay or Ypresian Clays)

The ONDRAF/NIRAS programme for geological disposal, currently at the methodological RD&D stage, focuses on the Boom Clay in Mol–Dessel, without however prejudging the site where a repository would potentially be implemented; Ypresian Clays are studied as an alternative host formation. The RD&D programme is essential because the disposal system to be designed has a unique character, in particular because it must provide maximum adequacy between the waste for disposal, the engineered barriers and the host formation. In this respect, ONDRAF/NIRAS has adopted a careful, systematic and stepwise approach aimed at verifying the absence of inescapable obstacles, whether in terms of safety (operational and long-term, classic and radiological) or feasibility.

Since the promising nature of the scientific and technical results obtained by Belgium as early as the 1970s on geological disposal in poorly indurated clay, in particular Boom Clay, still remains valid, both in terms of safety and feasibility, and has been progressively confirmed on various occasions, notably through peer reviews, ONDRAF/NIRAS is in a position to propose this type of solution for the long-term management of B&C waste.

The current RD&D programme aims to consolidate and refine the scientific and technical basis for the proposed solution. Peer reviews and acceptance of the conclusions by the academic and industrial worlds play an essential role in this regard. This is also necessary (but not sufficient) for the quality of the work of ONDRAF/NIRAS to be recognised by the public.

8.1.1 A programme being developed through progressive steps since 1974: chronological scientific and institutional reference points

The development of the Belgian programme for geological disposal is characterised by a series of decisions, first by SCK•CEN and then by ONDRAF/NIRAS, that have focused studies on Boom Clay in Mol–Dessel, with Ypresian Clays being studied in an exploratory way as an alternative host formation. These successive decisions were in conformity with international recommendations on the selection of favourable geological formations for deep disposal and the favourable opinions issued by the various review committees, which were asked, notably by Government, to give an opinion on the quality of the studies being conducted. The validity of the studies has also been confirmed several times since 1976 by different commissions and working groups asked by institutional bodies to give an opinion on various issues including, to varying degrees, radioactive waste management (Inset 13 just before section 8.1.2). However, the positive conclusions provided by these review committees, working groups and commissions have never led to a *formal* confirmation, at institutional level, of the direction followed by ONDRAF/NIRAS.

The RD&D programme for the geological disposal of B&C waste can be divided into three major phases that illustrate its progressiveness and the gradual transition from fundamental RD&D to (semi-)industrial demonstration activities and knowledge confirmation activities: the 1974–1989 phase, the 1990–2003 phase, and the current phase, which started in 2003. The RD&D programme has always been and is still carried out and reviewed within the scope of multilateral or bilateral international collaborations (Figure 34).

Figure 34 – International contacts within the scope of geological disposal programmes. Left: a group of visitors at the entrance to the Äspo tunnel, in Sweden (source: SKB; photographer: Curt-Robert Lindqvist); right: Nagra (Switzerland) and NUMO (Japan) visit the Belgian underground laboratory, HADES (source: EURIDICE).

8.1.1.1 1974–1989 phase (detailed in the SAFIR report)

In 1974, SCK•CEN launched an RD&D programme on the geological disposal of B&C waste. Given Belgium's choice, in the 1960s, of nuclear power to supply some of its electricity requirements (currently 54% [122]) and aware of the need for a solution for the long-term management of high-level and/or long-lived waste from the reprocessing of irradiated nuclear fuel, SCK•CEN, based in Mol, began a programme of studies on disposal of this waste in a stable geological formation. This solution was in line with international recommendations on the subject (for example [89, 114, 115]) and works conducted in other countries on the same topic.

Using in particular the catalogue of favourable formations for geological disposal in Belgium, established under the auspices of the European Commission (section 7.2.2.2 and [116]), SCK•CEN, assisted by the Geological Survey of Belgium, rapidly focused its efforts on the layers of poorly indurated clay at intermediate depths in the Campine, and especially on the Boom Clay.

The initial results of the characterisation of Boom Clay obtained by SCK•CEN, positive in terms of the formation's lithology and confinement capacity for radionuclides and chemical contaminants, led it to increase its research efforts and focus them in Mol–Dessel. Other factors also contributed to this decision:

- the on-site presence of a well-developed scientific infrastructure and researchers specialising in various disciplines, making it immediately possible to create a multidisciplinary research team;
- Mol–Dessel's status of "nuclear zone" on the regional zoning plan, which *a priori* allowed the creation of the infrastructures necessary for an underground laboratory;
- the issue of limiting costs for this first research programme by keeping it to a single formation and a single location.

In 1980, SCK•CEN began constructing the HADES (High-Activity Disposal Experimental Site) underground research laboratory in Boom Clay, in Mol. Given the lack of experience, both nationally and internationally, in the excavation of underground galleries several metres wide in poorly indurated clay, at a depth of around 200 metres, one of the main objectives of the initial RD&D programme was to assess and demonstrate the feasibility of such operations. The construction of HADES would prove that it was possible to build in this type of geological formation. This research tool, which was back then unique in the world, began operating in 1985 and a series of *in situ* experiments were quickly set up. HADES was subsequently extended several times (Figure 36 at the end of section 8.1.1), each extension phase enabling demonstration of additional feasibility (see the remainder of section 8.1.1 for more) and being characterised by the simplification of excavation conditions and the evolution of the types of lining, due to improvements in knowledge relating to the behaviour of the clay during and after excavation.

In the early 1980s, just after its creation, ONDRAF/NIRAS gradually took over some of the missions for which SCK•CEN was initially responsible, particularly the study of a solution for the long-term management of B&C waste. Since it had inherited a wealth of knowledge of great scientific value and a powerful research tool, it decided to go deeper into the studies undertaken by SCK•CEN on Boom Clay in Mol–Dessel. Furthermore, it did not have sufficient resources to have parallel and comparable studies of several potentially favourable host formations in Belgium.

In 1984, ONDRAF/NIRAS decided to prepare a summary of the works relating to geological disposal conducted in Belgium: the Safety Assessment and Feasibility Interim Report or *SAFIR Report.* This report, which followed a recommendation from the Evaluation Commission for Nuclear Energy in 1976 [123] and which was published in 1989 [124], was designed to enable the authorities to issue a first opinion on the qualities of the Boom Clay layer as a host formation, particularly in Mol–Dessel, and on continuing the associated RD&D programme. Above all, ONDRAF/NIRAS wanted to establish whether it was possible, from the studies conducted in the underground laboratory, to design a repository for B&C waste in Boom Clay which would be safe and feasible, including in terms of cost.

In 1990, the commission of Belgian and foreign experts appointed by the supervisory authority of ONDRAF/NIRAS to review the SAFIR report, confirmed its conclusions, namely that poorly indurated clays, and particularly the Boom Clay in Mol–Dessel, could be considered for the disposal of B&C waste. Indeed, Boom Clay had revealed itself to be of very low permeability and to have a strong capacity for retaining radionuclides, and therefore to have a good capacity for delaying their migration towards the surface. The SAFIR Evaluation Commission recommended that RD&D activities continue and that the study of other clay locations be included in the research programme, particularly the study of Ypresian Clays beneath the Doel zone [125].

> *"In fact, the SAFIR report only covers one option for the disposal of category (B) and (C) waste, namely that concerning the layer of Boom Clay beneath the nuclear site of Mol–Dessel; – the Commission considers that the competent authorities should explicitly authorise the continuation of feasibility research on this site; – although it is of the opinion that this option is acceptable, the Commission considers that it could prove useful to examine other locations for disposal in clay, such as the Doel nuclear site. Consequently, this site should be subject to the start of a characterisation study with exploratory boreholes."* [translation ONDRAF/NIRAS]

8.1.1.2 1990–2003 phase (detailed in the SAFIR 2 report)

In 1990, ONDRAF/NIRAS re-evaluated its methodological RD&D programme in order to bring it into line with the recommendations of the SAFIR Evaluation Commission. Notably, it included a preliminary characterisation of Ypresian Clays, paying particular attention to the Doel zone.

Since 1994, ONDRAF/NIRAS has given equal consideration to the study of geological disposal for reprocessing waste and for non-reprocessed irradiated fuel, in accordance with the provisions of the resolution adopted on 22 December 1993 by the Chamber [40], which imposes a suspension of commercial fuel reprocessing (see also Inset 13).

During the 1997–1999 period, the construction of a second access shaft to the HADES underground laboratory using semi-industrial techniques, in preparation for the laboratory's extension, was a new demonstration of the feasibility of this type of structure (Figure 36 at the end of section 8.1.1). This extension was to allow new experiments and especially the PRACLAY heater test (section 8.1.1.3).

In 2001, ONDRAF/NIRAS published the SAFIR 2 report, which summarises the advances made in terms of disposal in Boom Clay since 1990 [16, 17], according to which the studied solution was promising. Boom Clay seemed to be free of prohibitive defects in terms of safety and feasibility for the waste on which the studies had focused until then, namely vitrified category C waste from the reprocessing of irradiated fuel and, to a lesser extent, irradiated fuel. The SAFIR 2 report also presented the initial results of the studies relating to Ypresian Clays.

The SAFIR 2 report was subject to a review by a committee of Belgian academic experts set up upon initiative of the ONDRAF/NIRAS Board of Directors, followed by an international review requested by the Government and carried out under the auspices of the NEA, which confirmed its conclusions (Figure 35).

- In 2001, the conclusions of the Belgian review committee [126] emphasised, on the one hand, the fact that the research results did not highlight any prohibitive issue concerning the feasibility of a disposal system within Boom Clay, and, on the other hand, the need to continue the RD&D to reduce the remaining significant uncertainties. The review committee also mentioned that its recommendations for RD&D related to the priorities indicated by ONDRAF/NIRAS in the SAFIR 2 report. In particular, it considered that there needed to be a significant effort with regard to the disposal of waste other than vitrified category C waste. In preparation for the decision-making process, it also wanted to extend the programme to societal aspects and a review of all long-term management options (via an SEA) without compromising the research on disposal within Boom Clay.
- In 2003, the conclusions of the NEA review [10] pointed out in particular that the level of accumulated knowledge and experience would allow the transition to the process of selecting a site for implementing the disposal solution, while continuing RD&D in order to reduce the remaining uncertainties. However, just as ONDRAF/NIRAS did in the contextual document [18] that accompanied the SAFIR 2 report, they specified that the conditions for implementing such a solution were not being met: first, the solution had to enjoy societal support and its development had to be part of a shared decision-making process involving all stakeholders; and second, the legal and regulatory framework applicable to

disposal had to be further specified and supplemented. This review also highlighted the potential difficulties related to the industrial implementation of the engineered barriers as conceptualised.

In 2001–2002, the 80-metre-long construction of an extension to the HADES underground laboratory using industrial techniques demonstrated the industrial feasibility of constructing galleries in Boom Clay (Figure 36 at the end of section 8.1.1). This gallery, called the "connecting gallery", was built between the base of the second shaft and the existing facility, using the tunnelling technique combined with the use of an expanded concrete segmental lining (wedge blocks).

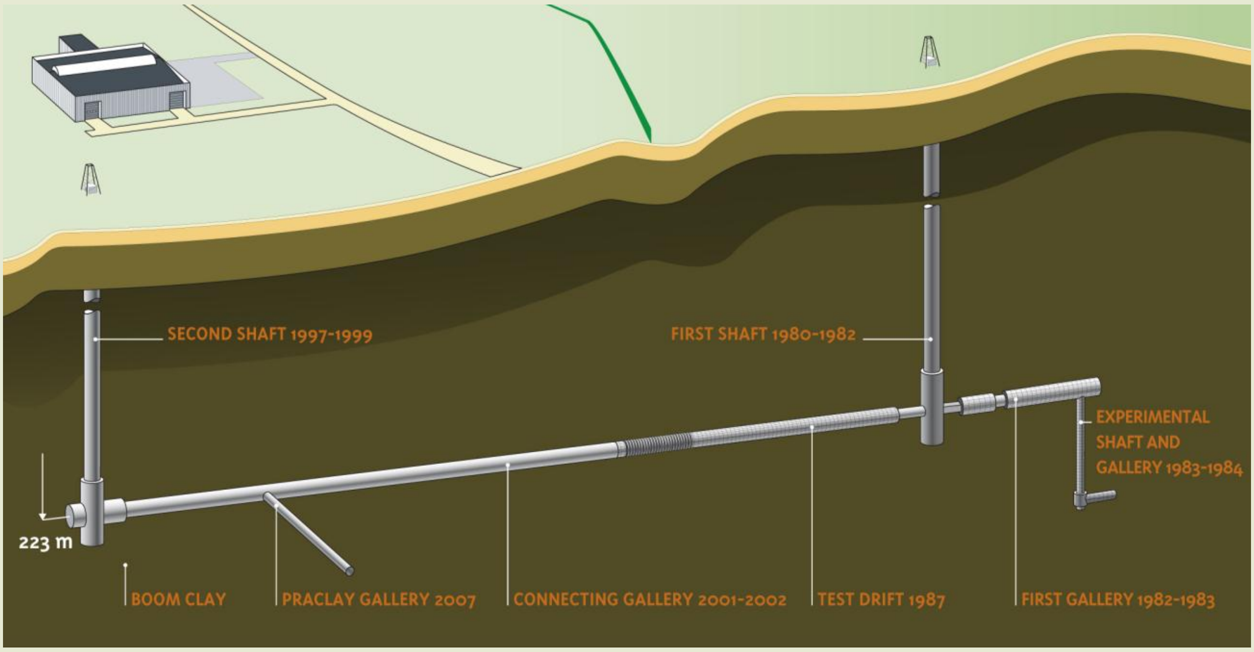
Figure 35 – The SAFIR 2 report, its technical overview, the contextual document that accompanied it and the report on the international review conducted under the auspices of the NEA.

8.1.1.3 Phase started in 2003

Since 2003, ONDRAF/NIRAS has re-evaluated its RD&D programme on geological disposal of B&C waste in order to bring it into line with the recommendations of the reviews of the SAFIR 2 report. In particular, it has refined and formalised the safety strategy [127] and the methodology for the safety assessments [128] and, from there, has modified the repository design, including the design and nature of the engineered barriers (section 8.1.2). Moreover, since then it also pays much attention to the compatibility of bituminised waste, which represent a significant proportion of category B waste (line c3-6 in annex A1), with the disposal environment.

In 2004, the supervisory authority of ONDRAF/NIRAS asked it to assess all possible strategies for the long-term management of B&C waste with a view to enabling a decision on the solution to be implemented and any associated conditions, while continuing the RD&D programme, and to plan for and begin a societal dialogue (section 5.2.2) [11]. It was on this basis in particular that the project "Waste Plan and SEA", with the associated societal consultation, was launched.

In 2007, the excavation (using the tunnelling technique combined with an expanded concrete segmental lining) of the PRACLAY gallery, perpendicular to the connecting gallery, was an important advance in terms of feasibility, because it demonstrated the possibility of building gallery crossings. The PRACLAY gallery is designed for the installation of an *in situ* large-scale (40 metres) heater test, planned for a minimum duration of 10 years, and aims to confirm the good behaviour of the clay and the gallery lining under the influence of a thermal load. The heating phase of this test, which follows a series of encouraging *in situ* tests on a metre scale, should begin in late 2011 – early 2012. Insofar as this test is a *confirmation* test, it is not necessary to wait for the results to make a decision in principle.



Freezing the soil with a view to constructing the first shaft

Excavating and fitting the lining of the first HADES gallery

First HADES gallery

Fitting the lining at the end of the second gallery, called “Test Drift”

Constructing the second shaft

Constructing the connecting gallery using a tunnel boring machine

Sealing the PRACLAY experiment

Constructing the chamber at the base of the second shaft

Connecting gallery

Figure 36 – History of the construction of the HADES underground research laboratory. HADES is used for fundamental *in situ* research experiments, long-term confirmation experiments and semi-industrial or industrial demonstration experiments. HADES is also a communication tool: every year, the underground laboratory is visited not only by Belgian and foreign specialists, but also by groups of people from a wide range of backgrounds (sources: SCK•CEN and EURIDICE).

Inset 13 – Institutional support provided indirectly, and even directly, to the Belgian geological disposal programme

In 1976, the Evaluation Commission for Nuclear Energy highlighted the interest of studies relating to geological disposal in clay. This commission, called the *"Commission des Sages"*, was created the previous year by the Minister for Economic Affairs in order to provide official institutions and public opinion with objective information with a view to the parliamentary debate on the energy policy called for by public opinion.

"The total volume of concentrates with high levels of radioactivity or plutonium in Belgium will amount to approximately 1200 m^3 per year in around 1990. After sufficient cooling, this waste will have to be disposed of in deep geological formations. This determines the disposal capacity to be created towards the turn of the century." (Group 8, 2nd part) [translation ONDRAF/NIRAS] [129]

"For Belgium, disposal (or discharge) into deep layers of clay seems most recommended. Studies conducted at CEN/SCK in Mol and abroad show that this objective can be achieved. The transition solution, i.e. storage of conditioned waste in bunkers, is necessary and also technically acceptable for an extended period (for example 50 years). This makes it possible to test the 'geological method' over a good number of years;" (Group 8, 2nd part) [translation ONDRAF/NIRAS] [129]

"A solution must also be found for the final disposal of highly radioactive waste and waste contaminated by alpha emitters. For Belgium, deep clay layers seem to be the best solution. It therefore seems appropriate to encourage research in this direction." (Chapter VIII) [translation ONDRAF/NIRAS] [123]

This report was not followed by the parliamentary debate on the energy policy which it was supposed to inform, but was distributed to all parliamentarians and therefore acted as information for the political world.

In 1978, the report *Eléments pour une nouvelle politique énergétique*, approved by Parliament, recalled the international consensus among experts that considered geological disposal in a suitably chosen continental formation as a reliable solution for the long-term management of conditioned radioactive waste [130]. It concluded as follows:

"Studies on the possibility of geological disposal of conditioned waste in Boom Clay are progressing satisfactorily. This approach to the issue requires continued research and demonstration work. However, right now, it seems like a realistic approach." [translation ONDRAF/NIRAS]

In 1982, the Evaluation Commission for Nuclear Energy updated its 1976 report at the request of the Secretary of State for Energy and, with regard to geological disposal, essentially completed it by recommending the continuation of current SCK•CEN studies and their extension to the geological disposal of non-reprocessed irradiated fuel [131].

"The studies launched by CEN in close collaboration with the national and international institutions concerned, with a view to examining the possibility of disposing of high-level conditioned waste in deep geological layers in clays must, as such, be continued." (Chapter VI) [translation ONDRAF/NIRAS]

"Measures must be taken so that irradiated fuel can be reprocessed within reasonable timeframes, for the following reasons […] without reprocessing, one must consider the conditioning of spent fuel elements in their entirety for their disposal in a geological formation." (Chapter VIII) [translation ONDRAF/NIRAS]

"A solution for the final disposal of highly radioactive waste and waste contaminated with alpha emitters is under development. For Belgium, deep clay layers seem to be the best solution. Intense and sustained effort and active continuation of current research in this field are therefore appropriate." (Conclusions) [translation ONDRAF/NIRAS]

In 1990, the Information and Survey Commission for Nuclear Security confirmed the interest for current studies on geological disposal [132]. This commission was created by the Senate in 1986 following the Chernobyl accident and renewed in 1988 with a broader role.

"The geological layer and final disposal characterisation reports must be made public, as ONDRAF/NIRAS has already opportunely done with regard to the SAFIR report. An evaluation commission for these reports, made up of independent experts from various disciplines is beneficial and necessary for the quality of the studies, as has just been demonstrated. These reports must be sent in a timely manner to Parliament and the Regional Councils." [translation ONDRAF/NIRAS]

In 1993, the resolution of the Chamber imposing a suspension of the reprocessing of irradiated fuel from commercial nuclear power plants [40] (resolution adopted 22 December 1993, confirmed by the Council of Ministers in the same year and reconfirmed by the Council on 4 December 1998) **made the Government, and consequently ONDRAF/NIRAS, responsible for,**

"prioritising research and development, including internationally, so as to be able to carry out eventually the direct disposal of irradiated fuel, without reducing the current research programme in the field of deep disposal of reprocessing waste." [translation ONDRAF/NIRAS]

In 2000, the AMPERE Commission, created by royal decree and responsible for formulating recommendations and proposals on the future choices for electricity production, mentioned Belgium's role internationally in terms of geological disposal in clay [133].

"Very large sums are dedicated to studies of the various concepts: thus, the current study programme for the disposal of highly radioactive waste in clay is part of a global programme that will have benefited from total financing by electricity producers of the order of 11 GBEF1998 at the end of the indicative global R&D programme in 2013. This allows Belgium to play a major international role in the study area and to gather experience with a view to disposal in deep clay." [translation ONDRAF/NIRAS]

In 2009, the GEMIX group, created by royal decree to conduct a study on the ideal energy mix for Belgium, noted in its recommendations [66]

that *"all necessary efforts must be made taking into account technological developments in order to reach a definitive solution that is acceptable from a societal perspective for the management of type B and C radioactive waste."* [translation ONDRAF/NIRAS]

Finally, the activities of ONDRAF/NIRAS are subject to an annual report to Parliament and are included in the official report that Belgium provides every three years at the meeting of the contracting parties to the Joint Convention [8], ratified by Belgium in 2002, since the first of these meetings (November 2003).

8.1.2 Description of the disposal system in poorly indurated clay

ONDRAF/NIRAS formalised its safety strategy [127] based on the functions that the different components of the disposal system (host formation + engineered barriers + waste) must ensure during the different periods of the system, as well as on the basis of the knowledge relating to Boom Clay. This strategy is therefore the result of a systemic approach and is used to support all of the choices in the design of the repository and the RD&D priorities. It also provides for the geological disposal system to be developed in stages and allows the RD&D results and new external requirements and/or conditions to be taken into account at each step. Its validity, and that of the design developed for the repository, must be confirmed for Ypresian Clays (section 8.1.6.2).

The essential elements on which ONDRAF/NIRAS relies in designing a disposal system for B&C waste in poorly indurated clay that ensures operational and long-term safety can be summarised as follows.

- *Long-term safety*:
  - *Confinement* of category C waste (lines b2-1, b2-4, b2-6, b2-7 and c2-1 in annex A1) must be ensured by engineered barriers for the period during which the properties of the host formation could become temporarily perturbed, in particular due to the rise in temperature caused by the waste (thermal phase). This period ranges from several hundreds of years for

vitrified waste to several millennia for non-reprocessed irradiated fuel (provided that it has been first cooled in surface storage for 60 years).

- ► *Isolation* of the repository from external perturbations, such as climate change, earthquakes or human activities, must be ensured by the clay layer and its geological environment.
- ► *Delay* in the migration of the radionuclides and chemical contaminants which will ultimately be released from the waste and the engineered barriers is essentially ensured by their retention in the clay.
- ► Design of the repository, including techniques and material choices, is carried out in such a way that the clay, which is the most important barrier with a view to long-term safety, is *not unduly perturbed*.

- ■ *Operational safety*:
  - ► The engineered barriers must ensure *radiological shielding* of the waste for the entire operational period (about 100 years), from the moment the conditioned waste is post-conditioned above ground to form supercontainers or monoliths (see below). They also aim to reduce the contamination risks in the repository.

The geological repository considered for B&C waste consists of a network of horizontal galleries built at mid-thickness of the clay layer, at a sufficient depth (Figure 37). Shafts lead to a main gallery which gives access to the disposal galleries, of smaller diameter. These galleries are divided into several sections dedicated to groups of wastes with similar characteristics (for instance their thermal output, their chemical composition or the nature of their conditioning matrix).

The system of engineered barriers considered for category C waste is based on the use of supercontainers aimed at ensuring full confinement of the radionuclides and chemical contaminants during the thermal phase. These supercontainers are the units formed by a watertight, carbon steel overpack (and the container(s) of vitrified waste or irradiated fuel that it contains) and the thick protective layer of cementitious material surrounding it (Figure 38). For handling reasons, category B waste is placed in concrete caissons and subsequently embedded in mortar to form monoliths (Figure 38). The supercontainers, as well as the monoliths, ensure radiological shielding to protect workers during operation and closure of the repository.

After emplacement of the waste, empty spaces in the disposal galleries are backfilled with materials chosen for their capacity to contribute to the system's overall safety. All access galleries and shafts are backfilled and sealed at the end of underground operations, if need be after a period of *in situ* controls. The system is then in a passive state.

After closure, the geological repository can be controlled from the surface, and future generations can prolong controls as long as they wish. Moreover, controls will be compulsory in case of disposal of irradiated fuel, in order to prevent the risk of nuclear proliferation.

The solution of geological disposal in poorly indurated clay is flexible enough to adapt to the potential variations identified in B&C waste volumes to be managed (section 10.2) and to the additional conditions to which it could be subjected on its implementation, such as those discussed in section 8.1.3.

The latest estimate of the non-discounted total cost, including margins for technological and project risks, of geological disposal in Boom Clay at a depth of approximately that of the HADES underground laboratory, assuming full reprocessing of all commercial fuel, amounts to some EUR_{2008} 3 billion [134].

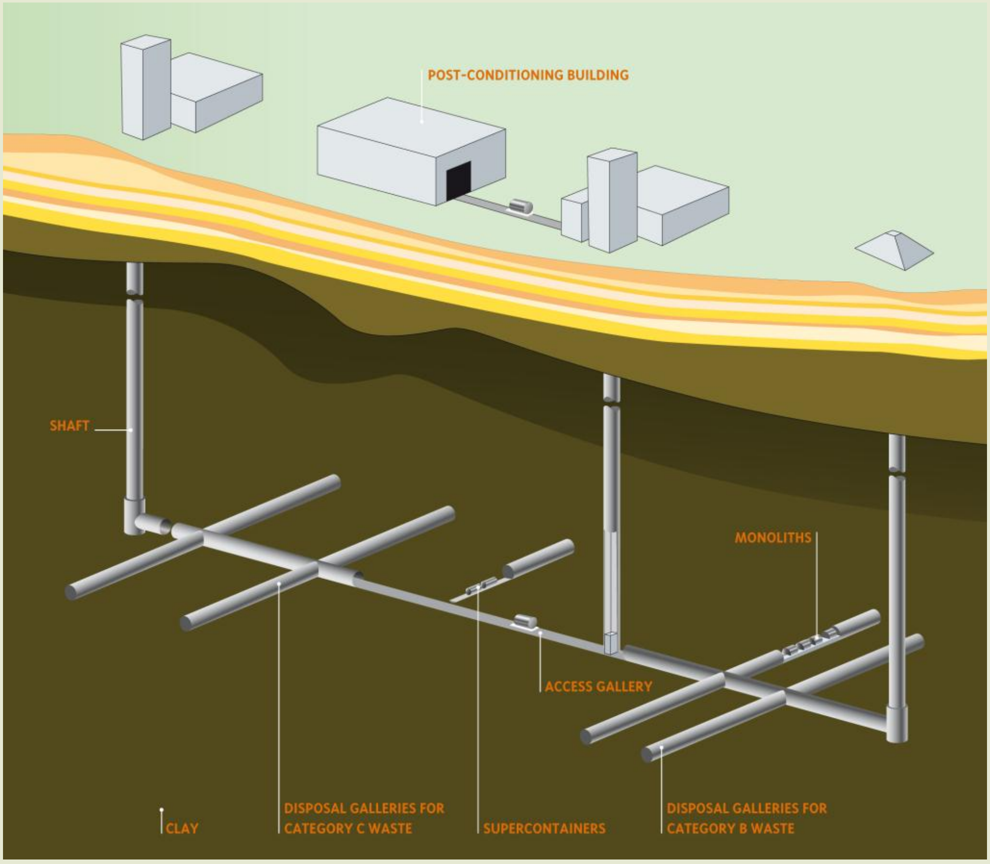


Figure 37 – Indicative diagram of the geological repository envisaged for B&C waste and of the surface facilities for the production of supercontainers and monoliths.

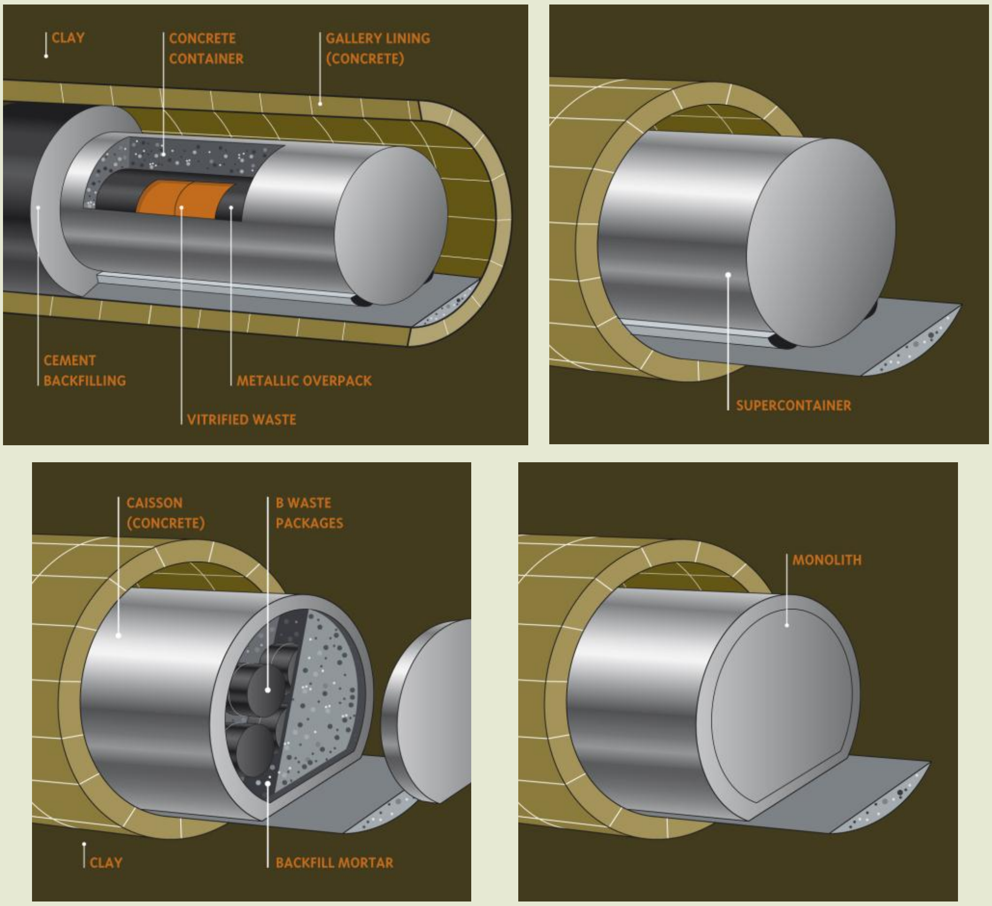


Figure 38 – Supercontainer for vitrified category C waste and monolith for category B waste in a disposal gallery.

8.1.3 Conditions for the development and implementation of a geological repository

The societal consultation initiated by ONDRAF/NIRAS in preparation for writing the draft Waste Plan and the SEA highlighted the importance that participants gave to reversibility and retrievability of the disposed waste and to control, along with knowledge transfer between generations and maintaining institutional memory of the repository [29, 31]. These aspects were largely confirmed by respondents to the legal consultation [34]. The views expressed, however, feature various ideas.

Given the importance that society attaches to the aspects of reversibility and retrievability, control and knowledge transfer and maintaining institutional memory of the repository, ONDRAF/NIRAS decided to factor them in as conditions in the development and implementation of geological disposal. The precise scope of these conditions will be examined from the scientific, technical, ethical, financial and safety angles, within the context of the societal dialogue that ONDRAF/NIRAS intends to implement without delay (section 9.4). At the very least, the following aspects will have to be examined:

- the periods over which the conditions must be satisfied;

- the absence of any negative impact on the short-term and/or long-term safety of workers and the population and on security and safeguards;
- interdependencies between the conditions.

Since retrievability leads to requirements in terms of controls and knowledge transfer, it could constitute the starting point for the societal dialogue [135]. These three conditions are explained below, with some aspects for consideration.

8.1.3.1 Retrievability

The importance of clarifying at national level the concepts of reversibility during operation and retrievability of disposed waste and their respective roles, considering that they must not affect long-term safety, has been recognised internationally. Despite this recognition and different initiatives on the subject (for example [136, 137, 138, 139]), it is clear that there are significant variations between the various national programmes for geological disposal with regard to the definitions of and roles assigned to reversibility and retrievability of waste.

Although the outlines and exact scope of the retrievability concept must be discussed between the stakeholders, including FANC, for the Waste Plan the concepts of "reversibility" and "retrievability" are defined as follows.

- "Reversibility" is the technical possibility of safely retrieving waste packages placed in disposal galleries that are not yet sealed using means identical or comparable to those used for their emplacement. Reversibility is strictly related to the operation of the repository: for each waste package, it begins with the disposal of the package and ends with the sealing of the gallery in which it has been placed. We then talk of retrievability [140]. The primary reasons that could result in having to recover the waste during operation are discovering that the package was damaged during its emplacement or finding that it was not properly placed in the repository. As such, reversibility is part of operational best practices often imposed on industrial operations and is provided for in the design analyses of ONDRAF/NIRAS.
- "Retrievability" of waste is the technical possibility of safely retrieving waste disposed of in sealed disposal galleries, if necessary using means other than those used for its disposal [140]. The extreme case for retrievability is the full mining excavation (mining out) of a completely closed repository.

Both these concepts are technical in nature and must not be confused with the concept of "adaptability", which is specific to the proposed decision-making process (section 9.1.3).

Given the results of the societal consultations, ONDRAF/NIRAS undertakes to
- ensure reversibility during operation;
- review the measures that could facilitate the potential retrieval of waste after the partial or complete closure of the repository for a period to be defined.

The issue of retrievability of disposed waste will be discussed at a societal level and further specified (section 9.4). Indeed, improving retrievability in the design and implementation of a disposal system cannot occur at the expense of short-term and/or long-term safety or security and safeguards, and could increase the cost of the disposal facility. Retrievability cannot therefore be a condition without restrictions (relating to the duration, costs, types of waste concerned, safety, security, etc.).

The discussion relating to retrievability will have to consider the following points in particular.

- FANC intends to introduce a requirement for reversibility during repository operation into the regulations, where the feasibility of reversibility will have to be demonstrated before disposal operations begin; it does not look like FANC intends to introduce the requirement of retrievability [141]. However, FANC considers that a designer of a repository should take measures proportionate to the risks related to the disposed waste in order to facilitate its possible retrieval, for example measures relating to the integrity of the waste containers or the facility to access the waste for a defined period.
- The disposal of radioactive waste is legally defined as being the emplacement of this waste in an appropriate facility without intention to retrieve [1, 7]. A geological disposal facility is therefore a facility designed to be the final destination of the radioactive waste, for which the long-term safety requirement does not lead to the requirement for retrieval of the waste. In this sense, the position of the Swedish National Council for Nuclear Waste (KASAM) regarding controls (section 8.1.3.2) is also applicable to retrievability. Therefore, it is not the responsibility of ONDRAF/NIRAS to make design and financing arrangements that would allow the disposed waste to be retrieved with a view to enabling future generations to put it to good use.
- Two elements ensure a certain degree of retrievability of disposed waste, at least for a while. However, so far the retrievability of waste has not guided the design work of ONDRAF/NIRAS.
    - *The degree of integrity of the container surrounding the waste.* Since the container that surrounds the waste provides radiological protection for the workers, its degree of integrity directly affects the measures to be taken to retrieve the waste.
        - Category C waste can in principle be retrieved relatively easily for a period in the region of 1 000 years. In fact, one of the essential elements on which the repository design is based is the requirement for complete confinement of the waste by the engineered barriers during the thermal phase (section 8.1.2), which is reflected in the use of supercontainers aimed at maintaining the integrity of the overpacks. This design, intended to ensure the long-term safety of the repository, therefore also favours relatively easy retrieval of the waste during a certain period. In the event of degradation of the cement casing surrounding still intact overpacks, additional measures would be needed in order to allow safe retrieval of the waste.
        - No minimum durability is stipulated for the design of monoliths for category B waste. However, even if the safety assessments consider (as a precaution) an "instantaneous" degradation of the monoliths after closure, it is difficult to conceive that these massive concrete structures would completely degrade on closure of the disposal galleries: even in their current design, a certain integrity period should be able to be guaranteed.

- *The repository's closure stage* (Figure 39). Access to the waste reduces as the steps to close the repository take place (backfilling and sealing galleries containing waste, then the main galleries, and finally the access shafts) and the direct and indirect costs (i.e. related to radiological risks for workers) for the safe retrieval of the waste increase simultaneously.

Additional design measures could have to be taken to facilitate further the retrieval of the waste over the considered period. Thus, the disposal galleries could be backfilled with a "light" cement material, clearly different from the materials used for the supercontainers and monoliths and which could easily be removed. The feasibility of such measures and their lack of impact on safety would have to be analysed on a case-by-case basis.

- Leaving the disposal galleries (partially) open and leaving the access shafts open to facilitate the retrieval of waste would affect the behaviour of the disposal system. Indeed, the longer the repository remains open, the more complex the evolution of the processes taking place in the vicinity of the waste (longer hydraulic, chemical and thermal transients, increase in microbial activity, etc.). Dedicated RD&D would thus be needed to verify on a case-by-case basis that leaving certain parts of the repository open would not have a negative impact on the engineered barriers and/or the host formation [135].

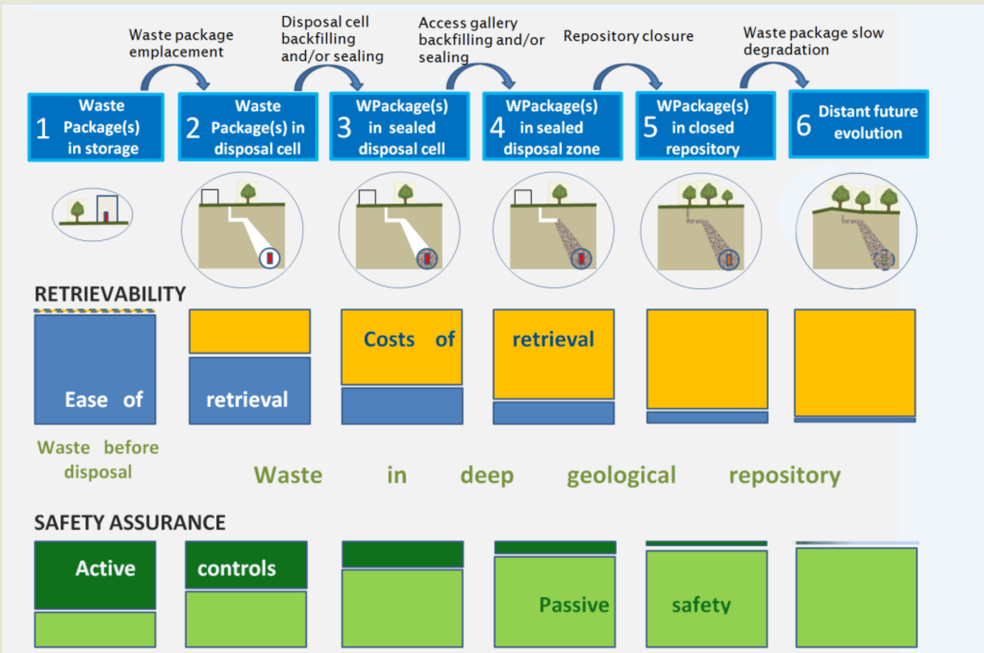


Figure 39 – Diagram of a disposal system's evolution over time, showing in particular the evolution in the degree of retrievability and passive safety [142].

8.1.3.2 Controls

Since a completely closed geological disposal facility is a management solution that protects man and the environment in a passive way, in other words without requiring human intervention, it does not have to be permanently controlled after closure to be safe: it is intrinsically safe as long as it has been correctly developed, optimised and implemented. However, this does not preclude planning for and implementing control measures, as highlighted by KASAM [101].

> *"A final repository should be constructed so that it makes inspection and controls unnecessary, without making inspection and controls impossible. In other words, our generation should place the entire responsibility for the final repository on future generations, but neither should we deprive future generations of the option of assuming responsibility."*

In addition to the controls which are or will be provided for in the regulatory framework, whether related to the licences, security aspects or the system of safeguards, additional controls during operation and/or closure and/or after complete closure of the repository are required by society in order to verify the proper functioning of the disposal system. These controls could in particular aim to verify the proper implementation of the backfill and seals necessary for the progressive closure of the repository or verify that the physicochemical phenomena taking place in the repository and their scale are as expected. After emplacement of the waste and (partial) closure of the disposal galleries, the physicochemical transients will indeed be significant (thermal emission, water saturation of the engineered barriers, oxygen consumption, etc.). One could verify in this way that the potential impact of the repository on its environment (temperature in the clay and surrounding aquifers, ground elevation, etc.) remains acceptable or within the standards.

ONDRAF/NIRAS undertakes to maintain the controls of the proper functioning of the disposal system that will arise in addition to the regulatory controls (Inset 14) for a period to be agreed with stakeholders (see also section 6.1).

Inset 14 – A few words about regulatory controls

Regulatory controls will be performed throughout the construction, operation and progressive closure of the geological repository, then after its closure. In particular, the controls will be related to the various licences required, but also the provisions in terms of security and safeguards.

In Belgium, FANC is responsible for security and supporting verification activities for compliance with safeguard measures, conducted under the auspices of the IAEA and Euratom. FANC is currently reviewing the legislation in terms of security. Control and surveillance measures in the field of safeguards are currently being defined by the competent international organisations [143].

In terms of regulatory controls, FANC currently allows, for example, after waste disposal [140]:

- a surveillance and monitoring programme after the disposal galleries have been sealed;
- a surveillance and monitoring programme after the complete closure of the repository. This programme, initially mainly focused on active measures (prevention of intrusions, surveillance of the state of the repository, etc.), gradually develops towards a purely passive programme in the long term (prevention of the risk of intrusion via permanent markings for example).

The periods for these surveillance and monitoring programmes have not yet been established.

The specifications of the controllability condition will be examined from various angles within the framework of the planned societal dialogue (section 9.4). It is however unrealistic to hope to be able to maintain them in an unlimited way over time (Figure 39). The step-by-step closure of the repository could be combined with a programme of controls over periods to be defined. Each step in the closure would reduce accessibility to the waste and improve passive safety, which in principle will make the controls increasingly indirect. In any case, the controls and associated instrumentation must not perturb the safety of the repository, for example by creating preferential pathways for water or radionuclides. Good use can be made of the experience acquired by ONDRAF/NIRAS and SCK•CEN in this area and in terms of instrumentation reliability within the scope of the *in situ* experiments in the HADES underground laboratory.

8.1.3.3 Knowledge transfer and maintaining institutional memory of the repository

Knowledge transfer and maintaining institutional memory of the repository are broad concepts that encompass

- the "marking" of the repository location and
- transfer of knowledge and know-how relating for example
  - to the disposal system (design, safety, scientific and technical grounds, etc.);
  - to the waste that the facility contains and the dangers that it presents;
  - to the proper functioning of the disposal system, as a basis for evaluating the results of controls. In this respect, knowledge transfer is also closely linked to controllability (including regulatory control) and retrievability aspects, as well as their respective timescales.

ONDRAF/NIRAS is committed to planning for the best possible transfer of knowledge to future generations. This transfer may be organised both locally and nationally, but also internationally, particularly through the reports to be supplied within the scope of international obligations. It could also be facilitated by the wide distribution in scientific literature of the scientific and technical grounds upon which the repository's safety and design are based.

The specifications for the knowledge transfer conditions related to the repository and the waste that it contains and to maintaining institutional memory of the location of the repository will be examined as part of the societal dialogue to be set up (section 9.4). However, it will be up to each generation to decide what knowledge and resources it wants to transfer to the next generation.

8.1.4 Key scientific and technical knowledge acquired from the RD&D programme relating to disposal in Boom Clay

The current disposal system for B&C waste in Boom Clay is, according to the present state of knowledge and assessments, able to ensure operational and long-term safety and is technically feasible. The remainder of this section gives an overview of the key knowledge acquired from the RD&D programme. More detail is given in the SAFIR 2 report [16] and in more recent publications, a list of which will be given in the RD&D programme currently being written (section 8.1.6).

8.1.4.1 Boom Clay as a barrier

The Boom Clay formation is present in the north-east of Belgium. Under the Mol–Dessel zone, it is approximately 100 metres thick and extends from around 190 to 290 metres deep. It slopes by 1 to 2% towards the north–north-east of Belgium. It is poorly indurated rock with very low permeability. Its performance as a barrier to the migration of radionuclides and chemical contaminants is summarised in Inset 15.

Inset 15 – Boom Clay as a long-term natural barrier to the migration of radionuclides and chemical contaminants

Boom Clay has various properties that make it a high-quality natural barrier to the migration of radionuclides and chemical contaminants towards the surface environment.

- It has a *very low permeability*. There is therefore practically no water movement within it and thus no radionuclide and chemical contaminant transport via this medium. As a result, transport is essentially diffusive, which means species migrate under the influence of their concentration gradient, not under the influence of the pore water movement. This property was revealed in part due to the experiments conducted over more than 20 years in the underground laboratory.
- It has a *strong retention capacity* for many radionuclides and chemical contaminants (sorption capacity, favourable geochemical properties, etc.). Their migration through the clay is thus considerably delayed.
- It displays a *significant buffer effect* with regard to chemical perturbations (for example introduction of oxygen during the excavation works and operation and diffusion of an alkaline plume from the concrete of the engineered barriers). The thickness of the clay that is effectively perturbed is therefore very limited.
- It is *plastic*. Therefore, any fractures and fissures that could occur in it, in particular by excavation activities, tend to close by themselves (self-sealing capacity).

Consequently, Boom Clay *does not present any preferential pathways for the migration of radionuclides and chemical contaminants* gradually released from the repository.

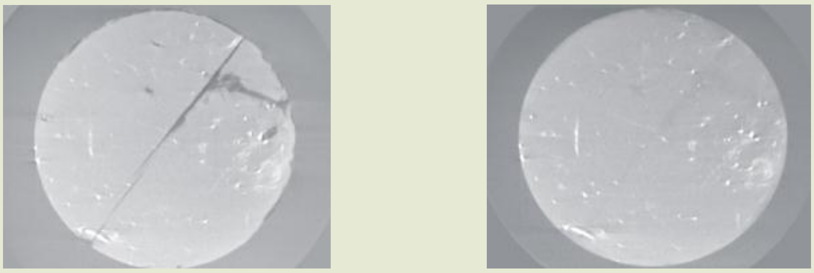


Illustration of the self-sealing capacity of Boom Clay. Left: clay sample in which a fracture has been induced; right: the same sample 4 hours after hydraulic saturation: the fracture has been sealed.

The entire Boom Clay formation (about 100 metres thick) consists of different layers more or less rich in clay. However, radionuclide and chemical contaminant transport properties are very homogeneous almost throughout the entire thickness of the Boom Clay. In addition, Boom Clay is present within simple geological structures, ensuring good lateral continuity: these two properties facilitate its characterisation.

Boom Clay is hydrogeologically, geochemically and mechanically stable over geological timescales, i.e. millions of years.

- The components of Boom Clay have remained unchanged since shortly after its formation, 35 million years ago. Over this entire period, natural changes (earthquakes, sea level fluctuations, glacial periods, etc.) have not altered its favourable properties.

- The migration of natural chemical species through Boom Clay has remained diffusive over at least the last million years.

The stability and barrier properties of Boom Clay are illustrated by natural analogues, *a natural analogue being a geological system where materials and/or processes similar to those expected in a disposal system are found*.

- The most remarkable natural analogue is the uranium deposit in Cigar Lake (Canada) [144]. With approximately 11% of known global uranium reserves, Cigar Lake is one of the richest and largest uranium deposits. Its importance with respect to the disposal of radioactive waste is due to two factors: on the one hand, it is formed of approximately 98% uranium dioxide (UO_2), which is the main compound of irradiated nuclear fuel, and, on the other hand, this highly pure uranium is protected from groundwater by a clay dome. The high-grade ore also enables very accurate analysis of the interactions between the uranium and its environment.

  Although located at the base of a highly permeable sandstone formation, the Cigar Lake uranium deposit has been preserved for approximately 1.3 billion years, essentially due to the presence of the clay cover, which has reduced groundwater penetration into the deposit and prevented the migration of the uranium. The deposit has remained intact during several mountain forming episodes (Rocky Mountains, Appalachian Mountains), several glaciation periods and significant uplift due to the erosion of over 2.5 km of sedimentary rocks. Currently situated at a depth of 430 metres, it is in fact so stable that no chemical or radioactive signature can be detected from the surface.

- Perfectly preserved (and non-fossilised) tree trunks have been discovered in Dunarobba (Italy) within a clay mud flow dating back around two million years. The presence of clay has thus prevented the decomposition of the plants for this entire period [144].

Finally, clay is used (in the form of bentonite) in almost all geological disposal concepts developed abroad, for example, as protection buffer material, backfill material and/or sealing material, precisely due to its inherently favourable properties, described above for Boom Clay.

The formations located on either side of the Boom Clay are sandy and aquifers. The sands overlying the Boom Clay form the second largest aquifer for the capture of drinking water in Belgium and the main one for the country's north-east. The aquifer located beneath the Boom Clay is only slightly productive. The presence of these aquifers is a particular point of attention for ONDRAF/NIRAS, both from the point of view of their radiological protection and the limitation of physicochemical perturbations (thermal impact, presence of chemically toxic elements, etc.) and from the point of view of the risk of human intrusion. All the long-term safety assessments conducted so far show that Boom Clay is extremely effective in retaining radionuclides and chemical contaminants, such that the impact of a geological disposal facility on the aquifers and individuals who consume the water would be very small and in any case lower than all current standards.

8.1.4.2 Feasibility assessment

Feasibility refers to the possibility of *constructing*, *operating* and *closing* a repository in accordance with the established specifications, taking into consideration engineering constraints, operational safety constraints, constraints in terms of reversibility during operation and controls, possible constraints still to be defined related to the retrievability condition and financial constraints.

The key knowledge acquired in terms of feasibility assessment is as follows:

- demonstration of the possibility for the industrial implementation of shafts and galleries within Boom Clay at over 200 metres depth, as well as the possibility of building gallery crossings, while limiting geomechanical perturbations in the clay, these demonstrations being the first of their kind;

- demonstration of the artificial nature of the fractures observed in the Boom Clay during excavations: these fractures, which are caused by excavation, self-seal over time;
- demonstration of the possibility of implementing a quality seal in a shaft;
- demonstration of the possibility of backfilling the empty spaces between the lining of the disposal galleries and the supercontainers or monoliths using a cement grout;
- possibility of handling the supercontainers and monoliths in shafts and galleries according to known industrial methods;
- known and industrially proven behaviour of carbon steel in a cement environment, which allows the prediction of very good corrosion resistance for the metallic overpack and therefore guarantees the confinement of category C waste during the repository's entire thermal phase;
- capacity to estimate disposal costs and associated margins for technological and project risks.

8.1.4.3 Integrated view of the evolution of the disposal system

A significant effort is currently under way to develop an integrated view of the evolution of all the physicochemical processes taking place within the waste, the engineered barriers and the first metres of clay at key moments in the disposal system's evolution (Figure 40). This integrated and time-dependent view of the system's behaviour is a valuable aid, not only for defining the disposal system's expected evolution scenario to be taken into account in the safety assessments, but also for establishing RD&D priorities.

As part of the integration and in support of the safety assessments, a knowledge management system has also been developed in order to facilitate data sharing, the traceability of decisions made and multidisciplinary integration, and therefore ensure the consistency of the data, models and scenarios used. This system also contributes to the continuity of the necessary knowledge and expertise for the entire development and implementation period of a geological disposal solution.

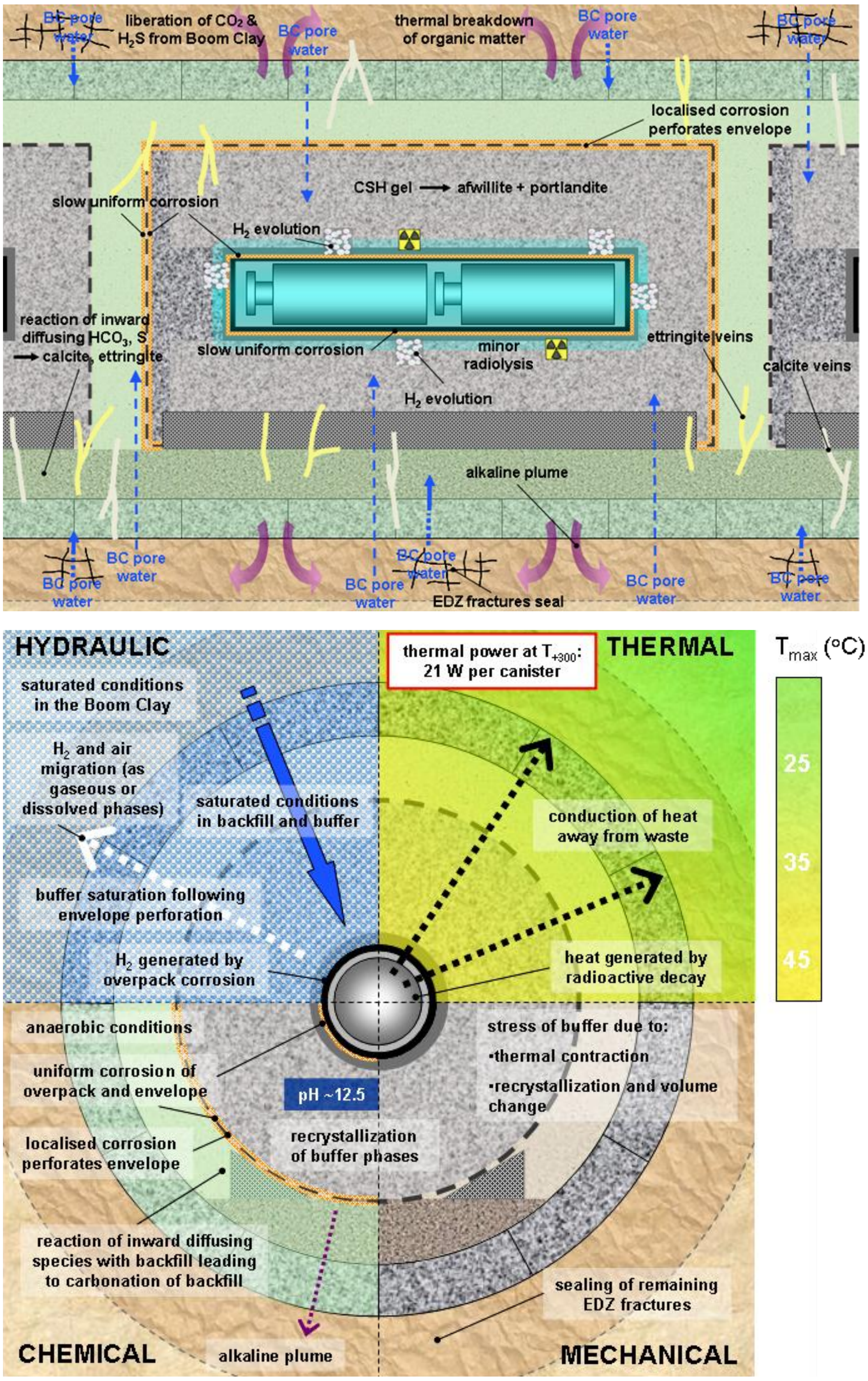


Figure 40 – Example of an integrated view of the disposal system's behaviour: longitudinal and transversal cross-sections of a disposal gallery for vitrified waste, showing the thermal, hydraulic, mechanical and chemical processes taking place near a supercontainer approximately 300 years after its disposal, which is after the peak in temperature rise caused by the waste [145]. This same kind of integration has been implemented for various key moments in the disposal system's evolution. The integrated understanding of its behaviour contributes in particular to identifying the most important processes for safety. Minute consideration of all the processes is not however necessary in long-term safety assessments.

8.1.4.4 Long-term safety assessments

The impact of the repository in the long term was assessed on the basis of the considerable knowledge and expertise available at both national and international level. The uncertainties about the evolution of the disposal system were analysed by taking them into account in a reasoned manner in a range of scenarios. These scenarios are the reference scenario, which describes the expected evolution of the disposal system, and its variants, a number of other possible but less probable evolution scenarios, and human intrusion scenarios.

The main findings concerning the assessment of the long-term safety under normal conditions have been obtained for a repository assumed to be built in the middle of the 100-metre-thick layer of Boom Clay in the region of Mol–Dessel. They can be summarised as follows [16].

- Boom Clay is the main contributor to long-term safety.
- Engineered barriers make an effective contribution to long-term safety that largely exceeds requirements.
- Waste matrices play a minor part in the long-term safety, except for the UO_2 matrix of nuclear fuel.
- The peak dose generated by the repository is at least 10 times lower than the regulatory limit:
  - the main contributors to the dose are the fission products that are not retained in the Boom Clay (^{129}I, ^{36}Cl, ^{14}C, etc.);
  - actinides (U, Pu, Am, Cm and Np) only make a very small contribution to the dose;
  - most radionuclides decay to insignificant levels within the engineered barriers or during their transport through the Boom Clay.
- The most mobile fission products leave the Boom Clay after some tens of millennia; actinides leave the Boom Clay after several hundreds of millennia. In both cases, the quantities are negligible.
- The presence of a geological repository in the Boom Clay has no negative impact on the aquifers on either side of the Boom Clay and does not preclude their exploitation as sources of drinking water.

The conclusions of the safety assessments are based on cautious, sometimes even pessimistic assumptions, which introduce significant safety margins in the results obtained. These assumptions are of very different types, as illustrated below [16].

- The geochemical conditions imposed by the supercontainer's cement material are favourable for the significant durability of the overpack in carbon steel. Its lifespan would be about 100 000 years, although a confinement lasting several millennia is enough to ensure safety, given the excellent barrier properties of the Boom Clay.
- Certain processes that help to limit the release of radionuclides and chemical contaminants are deliberately ignored, like the fact that
  - the corrosion of the primary waste package is slow (although this package is assumed to corrode instantly);
  - certain radionuclides are retained within the degraded concrete and metallic barriers (although this retention is not taken into account);

- ► the migration of radionuclides and chemical contaminants is delayed by the category B waste matrices (although this delay is not taken into account).

- The assumptions concerning the degree of radiological exposure of individuals are very pessimistic.

For example, an individual living near the disposal site and extracting drinking and irrigation water from a deep well situated just above the Boom Clay layer, where, according to calculations, the highest concentrations of radionuclides will be found, would be exposed to the highest radiation doses between 100 000 and 1 million years after repository closure (Figure 41). At maximum exposure, after about 200 000 years, the doses are still 10 to 30 times below the internationally accepted limit of 0.1 to 0.3 mSv per year and over 250 times lower than the naturally occurring annual dose in Belgium (2.5 mSv per year).

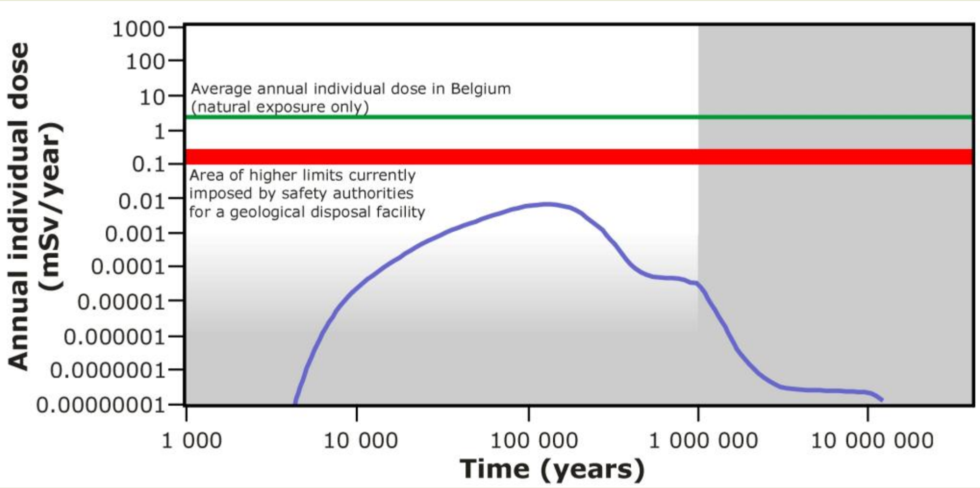


Figure 41 – Estimated annual individual dose due to the presence of a geological disposal facility in Boom Clay, assuming a reference scenario (adapted from [16]). The unshaded part corresponds to dose levels considered to be of radiological significance and to the minimum period of geological stability, i.e. a million years.

Given the significant uncertainties about future lifestyles in the vicinity of a possible geological repository site, other types of calculation are also performed to assess the impact of such a repository. An example is the estimated total radiotoxicity flux from the repository, i.e. the estimate of the annual radiological impact on individuals due to the hypothetical ingestion of all radionuclides released into the environment. This can be compared to natural radionuclides present in the clay layer or the radiotoxicity flux resulting from other activities practised today. The radiotoxicity flux from a geological repository of irradiated fuel with a surface area of one square kilometre built in poorly indurated clay is, for example, significantly lower than the radiotoxicity flux from fertilisers that are applied annually per square kilometre on the agricultural lands of Flanders (order of magnitude of 10 Sv/km^2/year — Figure 42) [146].

Dose: sum of the products obtained by multiplying the equivalent dose of radiation received by each tissue or organ by the weighting factor expressing the sensitivity of this tissue or organ to radiation. The word "dose" is often used instead of "effective dose"

Radiotoxicity: hypothetical dose resulting from ingesting radioactive substances, equal to the sum of the products of each radionuclide's activity level at a given moment by its dose ingestion factor

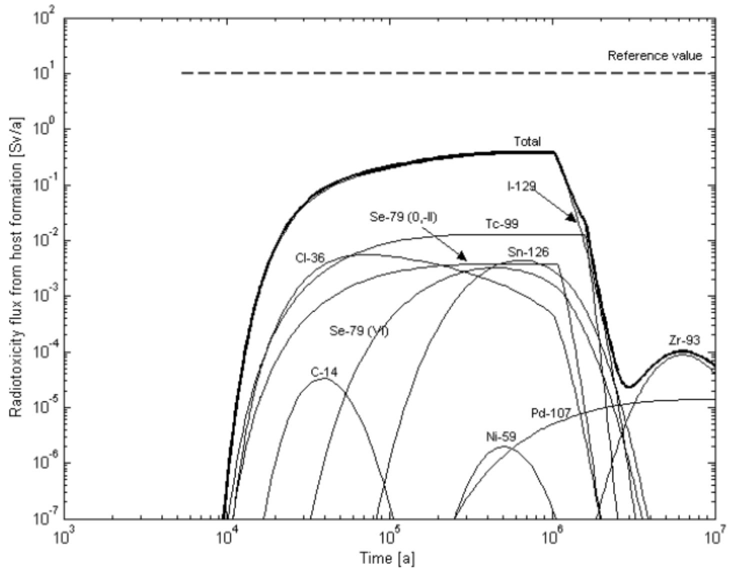


Figure 42 – Radiotoxicity flux resulting from a one square kilometre geological disposal facility of irradiated fuel in Boom Clay. The reference value corresponds to the flux from fertilisers applied annually per square kilometre on Flemish agricultural lands [146].

The assessment of the altered evolution scenarios (drastic rise in sea level, earthquakes, glaciation, premature rupture of the engineered barriers, etc.) and human intrusion scenarios does not result in conclusions that differ fundamentally from the ones above.

In general, the long-term safety assessments results are consistent with the results obtained within the scope of the other national programmes in the field of geological disposal, which enhances confidence in the assessments.

Long-term safety assessments of a geological disposal system, which follow an iterative approach of continuous refinement, are prepared over several years. Given the significant lateral continuity of the Boom Clay, the current conclusions of these assessments are valid to a large extent for a wide area of Boom Clay. Given the differences between locations (depth, thickness, composition of pore water, etc.), certain data needed for the safety assessments will however only be accurately established after the choice of one or several potential disposal sites. A detailed characterisation of the host formation at the identified location(s) will be needed to enable specific safety assessment(s) of this/these potential site(s), the results of which will then be submitted to the competent authorities.

8.1.5 Ypresian Clays compared to Boom Clay

In Belgium, not much is known about Ypresian Clays at depth. Several studies and exploratory boreholes have been carried out on the initiative of ONDRAF/NIRAS (Figure 43) [121]. A full interpretation of the results is still in progress.

Figure 43 – Exploratory drilling and core drilling for Ypresian Clays at Kallo.

In the extreme north-west of the country, Ypresian Clays present geological characteristics that are close to those of Boom Clay (Inset 15 in section 8.1.4.1). It is therefore likely that the development of a disposal system in Ypresian Clays may benefit from the knowledge acquired so far for Boom Clay (comparable geologies, transport processes controlled by diffusion and characterised by significant retention of radionuclides and chemical contaminants, possibility to transfer methodologies and experimental techniques, etc.).

Ypresian Clays have several potential advantages as a host formation over Boom Clay:

- they are present in certain locations at greater depths than Boom Clay;
- they present several areas much richer in clay minerals than Boom Clay, these minerals being the source of the retention of certain radionuclides and chemical contaminants and the formation's self-sealing capacity;
- they are surrounded by saline aquifers;
- they are topped by other clay formations that form a natural multi-barrier system.

However, certain characteristics of Ypresian Clays constitute potential difficulties, which do not seem insurmountable but should be analysed in more detail if the need arises. For instance, given that Ypresian Clays are very prone to swelling, the construction of underground facilities within them, at depths of about 300 to 400 metres, raises questions. Furthermore, the presence of salt water imposes different geochemical conditions to those in Boom Clay, which could impact the corrosion of the metallic engineered barriers and the migration of radionuclides and chemical contaminants.

Finally, Ypresian Clays have specific characteristics that would merit particular attention, such as the presence of structural discontinuities (faults) and a lower ability to dissipate heat than Boom Clay. Water circulating in the geological environment of these clays would also merit further scrutiny.

8.1.6 Principal future RD&D activities for the development and gradual implementation of a geological repository

Given that the continued development of a geological repository and its gradual implementation span several decades, the future RD&D programme needs to be flexible and evolve according to evolution in the societal, scientific, technical and economic context. It is likely to have to be adapted, for example, if the decisions made by the competent authorities differ significantly from the current outline of decision-making process (section 9.2), if unforeseen conditions are imposed on repository implementation, or if unexpected RD&D results call for additional investigations. The RD&D will also have to take into account the concerns highlighted within the scope of the past societal consultation, the legal consultation relating to the draft Waste Plan and the SEA, and the participative process which will accompany the further development of a geological disposal facility.

In concrete terms, the RD&D will have to establish the arguments in support of the decisions marking out the decision-making process (section 9.2). Thus, it will aim to confirm, refine and integrate the knowledge acquired (so as to reduce remaining uncertainties and increase safety margins), develop certain areas of knowledge (particularly with regard to Ypresian Clays), demonstrate directly or indirectly all aspects not yet demonstrated in the construction, operation and closure of a repository, and demonstrate cost control. The protection of the aquifer resources is one of the major concerns of ONDRAF/NIRAS, and studies on this subject will be continued and developed as needed.

The key areas of RD&D and their objectives may be summarised as follows. They are developed in the RD&D programme currently being written by ONDRAF/NIRAS for publication. This programme identifies the RD&D priorities with a view to establishing the first safety and feasibility case (SFC1 — see also section 9.2), while already identifying longer-term RD&D subjects.

8.1.6.1 Geological disposal in Boom Clay

- *For the host formation*:
  - Setting the acceptable perturbations (thermal, hydraulic, mechanical, chemical, etc.) in the Boom Clay. (This includes taking into consideration indirect perturbations caused by the presence of certain compounds in the materials used for constructing the engineered barriers.)
  - Assessment of the perturbations generated in Boom Clay by the production of gas after the repository is closed (and analysis of their impact on the repository design).
  - Confirmation, through the *in situ* PRACLAY experiment, of the capacity of Boom Clay and the gallery linings to support the thermal load imposed by heat-emitting waste, this load being one of the most important transients to

which the repository and host formation will be subject. PRACLAY should consolidate the results obtained by small-scale *in situ* tests and help support confidence in the models, their base assumptions and their predictions. This decametre-scale test lasting ten years has been designed to be independent of the design of the engineered barriers and the type of heat-emitting waste. The results relating to the initial heating phase, during which the thermal gradient will be at its peak, should be available in 2013–2014.

- Detailed understanding of the retention phenomena of radionuclides and chemical contaminants by Boom Clay.
- Assessment of the compatibility of planned uses of the subsoil (exploitation, including the capture of drinking water, exploration, etc.) with the presence of a geological disposal facility in Boom Clay.
- Confirmation of the long-term stability of the geology of Boom Clay in terms of depth, thickness, homogeneity and lateral continuity.
- Confirmation of the long-term stability of the geology of Boom Clay in the event of earthquakes and climate change.

- *For the waste*:
  - Verification that new types of anticipated waste (for example irradiated fuel with higher burnup than at present) do not raise new issues in relation to those already taken into account in the studies.
  - Refinement of the understanding of the durability of glass and UO_2 matrices in a cement environment.
  - Improved knowledge of the characteristics of irradiated fuel taking into account their intrinsic evolution during the storage period needed for their cooling, and consideration of this evolution in the studies relating to their conditioning and post-conditioning.
  - Confirmation of the compatibility of the bitumen matrix with Boom Clay. The swelling of Eurochemic bituminised waste and the resulting gas pressures are indeed significant.

- *For the facilities*:
  - Demonstration of each of the fabrication and handling steps for the supercontainers and monoliths, and verification of the reinforcement requirements (including in case of dropped packages).
  - Definition of the requirements relating to the sealing of galleries and shafts, and refinement of the sealing strategy to be implemented (taking into account any retrievability period).
  - Establishment of the operational requirements in terms of the presence of gas during disposal and analysis of the impacts on the repository design (for example on the ventilation), including the engineered barriers.
  - Practical application of the regulations in terms of security and safeguards.

- *For the implementation conditions for a repository*:
  - Analysis, from the scientific and technical, and safety and financial angles, within the scope of the societal dialogue to be implemented (section 9.4), of the conditions for the implementation of geological disposal in terms of the controllability of the repository (during its operation, progressive closure and potentially after closure), the retrievability of the disposed waste and knowledge transfer (including institutional memory of the repository

location), in order to define their respective objectives, scope and limitations and be able to incorporate them into the disposal project, by starting additional RD&D activities if necessary.

- *For safety and environmental impact assessments*:
  - Assessment of operational safety.
  - Refinement of the methodologies for managing uncertainties in the radiological safety assessments of the geological disposal system and the environmental impact assessments.
  - Refinement of the radiological safety assessments of the disposal system according to a range of scenarios (and their variants). These assessments must notably be used to ensure that the quality of the water resources is not endangered by the presence of the repository.
  - Refinement of the impact assessments of chemical contaminants released by the disposal system so as to ensure, in particular, that this impact does not endanger the quality of the water resources and, more generally, does not unacceptably affect the disposal system's environment, including the surface environment, and man.
  - Refinement of the impact assessments of the temperature increase on physicochemical conditions and underground processes (for example flows), biological diversity, flora, fauna and ground elevation.
  - Refinement of the reliability assessments of the models and simulations.
  - Integration of all the arguments relating to the different components of the disposal system on which safety relies and judgement related to the confidence in this safety.

- *For optimisation of the disposal system*:

  Optimisation of the disposal system must

  - focus on the disposal system *as a whole*, in order to avoid optimisation of part of the system leading to a reduction in the protection provided by the system as a whole;
  - take into account both the *safety* objectives to be achieved *and* the relevant *socio-economic factors*, so as to provide an optimal technical solution that is also acceptable from a socio-economic perspective, *without the consideration of socio-economic factors being detrimental to safety*.

  The optimisation process for the disposal system will focus mainly on repository design, including the engineered barriers, and will be carried out in consultation with FANC (see particularly [55, 147, 148]).

  The way in which the process for *choosing an appropriate site for the repository* is incorporated into the optimisation process will inevitably have to give significant consideration to societal factors (see also Inset 18 in section 9.2.3).

8.1.6.2 Geological disposal in Ypresian Clays

Insofar as Ypresian Clays present characteristics similar to those of Boom Clay, it is reasonable to assume that the safety strategy developed for geological disposal in Boom Clay can be applied to geological disposal in Ypresian Clays, that the same type of underground facility design can be used, and that most of the knowledge relating to

Boom Clay is valid for Ypresian Clays. The safety strategy takes an iterative approach, which therefore allows stepwise adjustments if necessary.

Consequently, and as a starting point, the scientific, technical and safety knowledge applicable to geological disposal in Boom Clay has been transferred “as is” to geological disposal in Ypresian Clays. The current systematic assessment of Ypresian Clays should provide an answer to the following questions.

- To what extent is the knowledge developed for a repository in Boom Clay transferable “as is” to a repository in Ypresian Clays (for example the effect of expected climate evolution)?
- To what extent is the knowledge relating to a certain number of base parameters, such as the mineralogy or chemistry of pore water (for example self-sealing, which is notably controlled by the presence of swelling clays), transferable from Boom Clay to Ypresian Clays?
- To what extent must detailed studies be started to determine parameters specific to Ypresian Clays or develop specific models for them (for example specific geomechanical parameters to assess the feasibility of excavation)?

The current results of ongoing studies suggest that the focus will probably have to be placed on the feasibility of excavation, the origin and impact of structural discontinuities, determining thermal conductivity, determining the hydrogeological context, improving the knowledge of pore water composition, and the possible impact of any vertical heterogeneity.

The results of additional studies and scoping calculations will be used to determine whether the safety strategy should be adjusted or whether it is possible to conduct a first assessment of Ypresian Clays as a potential host formation. The RD&D programme relating to Ypresian Clays will then be developed and adapted based on the results of this assessment.

Current knowledge suggests that it will not be necessary to construct an underground laboratory in Ypresian Clays. If the results of the research and future assessments lead to retaining the alternative of Ypresian Clays until an advanced stage in the decision-making process, and if the decision is made to build a repository in Ypresian Clays, if necessary an underground characterisation facility could be built, in other words a research facility located on the site of the future repository.

8.1.7 Cost of RD&D

The total cost of RD&D activities for geological disposal in Belgium, including the costs of the underground laboratory, for the 1974–2014 period, is estimated at approximately EUR_{2008} 360 million, which is approximately EUR 9 million per year.

The cost of future RD&D activities will be largely determined by the exact scope of the future decision in principle and possible additional societal requests. Thus, if the solution of geological disposal in Ypresian Clays needs to be subject to highly detailed studies, a substantial effort, approximately equivalent to the current annual RD&D effort for Boom Clay will be necessary. Investments required for the excavation of an underground characterisation facility could eventually be added to this. (It is difficult to put a figure on these investments in view of the uncertainties regarding the feasibility of mining constructions in poorly indurated and swelling clay at a depth of 300 or 400 metres.) The total investment in RD&D is still likely to be less for Ypresian Clays than for Boom Clay, in view of the considerable knowledge about Boom Clay.

8.2 In a single facility

According to ONDRAF/NIRAS, category B and category C wastes must be managed in the long term within the scope of a management solution — geological disposal — which, on the one hand, is common to both types of waste, since the risk they pose in the long term stretches over similar timescales, i.e. several tens or hundreds of millennia, and, on the other hand, is implemented at a single site, since their respective volumes are such that different facilities cannot be justified. A geological disposal facility can however be designed and operated in such a way that waste with different properties is placed, possibly sequentially, in different parts of the repository (see also section 10.2.5).

8.3 On Belgian territory

ONDRAF/NIRAS considers that B&C waste (as well as the other waste for which it is responsible) must be managed within a national framework and, therefore, on Belgian territory. Since Belgium decided in the past to use nuclear energy to produce a large part of its electricity, and since most of Belgium's radioactive waste directly (operation) or indirectly (dismantling) originates from the nuclear fuel cycle, it is indeed Belgium's responsibility to ensure the management of its radioactive waste. (Currently, over 50% of the electricity produced in Belgium is from nuclear origin, which according to the IAEA puts Belgium third in the world after France and Slovakia, with regard to the share of nuclear energy in the total domestic electricity production [149].) The choice of a national management policy is however compatible with the establishment of international collaboration, which ONDRAF/NIRAS has always done and will continue to do.

The position of ONDRAF/NIRAS is in line with the recommendations and regulations in force at international level, which emphasise each country's responsibility to manage its own radioactive waste. This was notably included in the preamble of the Joint Convention of 1997, itself transposed into the Belgian legal and regulatory framework in 2002 [7].

> *"vi) Reaffirming that the ultimate responsibility for ensuring the safety of spent fuel and radioactive waste management rests with the State;"*
>
> *"xi) Convinced that radioactive waste should, as far as is compatible with the safety of the management of such material, be disposed of in the State in which it was generated, whilst recognizing that, in certain circumstances, safe and efficient management of spent fuel and radioactive waste might be fostered through agreements among Contracting Parties to use facilities in one of them for the benefit of the other Parties, particularly where waste originates from joint projects;"*

Several countries are already actively involved in this process: they have made a decision in principle in favour of geological disposal of their high-level and/or long-lived waste on their national territory, or are even about to begin the construction of such a repository (Inset 10 at the end of section 5.2.3), and several of them have simultaneously banned the disposal of foreign waste on their territory, this ban being a prerequisite in these countries for a national solution to be accepted by society.

Furthermore, even if it is possible, and even probable, that shared geological disposal facilities (or regional repositories) will become available in the future at European or international level, this prospect is currently too vague to be taken into consideration when defining a management policy. Thus, the summary report of the third review meeting of the contracting parties to the Joint Convention, which took place in May 2009, indicates that the issue of shared repositories has not recorded any practical progress [73].

> *"20. The subject of regional repositories was mentioned by several Contracting Parties with small nuclear programmes or with limited waste management programmes. However no real practical progress has been achieved up to now. It is suggested that further cooperation between Contracting Parties would facilitate progress in this important issue."*

Although allowing for economies of scale, the solution of a shared repository also raises several questions, particularly regarding legal difficulties related to the definition of the parties' obligations (maintenance of responsibilities for their own national waste, reciprocity, etc.) and the transboundary movements of waste. From the points of view of safety, ethical principles, implementation process and scientific and technical grounds, the development of a shared geological repository also imposes the same requirements (if not stricter) as a national repository in terms of, for instance, the variety of waste to be considered or the difficulties of selecting a site.

Finally, the prospect of a shared solution in no way reduces the need for each country to have a national plan for radioactive waste management, as well as the human and financial resources necessary to implement it, including a RD&D programme and a financing system. The countries participating in the development of a shared repository should indeed be able to contribute to it both scientifically and technically, as well as financially, and cannot exclude the eventuality of the venture failing, which would result in them having to resort to a national management solution. Furthermore, the reciprocity principle means that any country that is party to a multinational agreement on the implementation of a shared repository is likely to accommodate all of the waste concerned from the countries party to this agreement on its territory.

8.4 As soon as possible

Considering the requirements of sound management, as well as the ethical principles of intragenerational and intergenerational equity, ONDRAF/NIRAS considers that a geological disposal facility in poorly indurated clay (Boom Clay or Ypresian Clays) must be operational as soon as possible, but with the pace of development and implementation of the solution needing to be proportionate to its scientific and technical maturity, as well as its societal support. In light of the scientific, technical, societal and regulatory constraints to be taken into account, this is not possible before 2035–2040. This necessity is broadly justified in the same way as the need for a decision in principle as soon as possible (section 5.2). Its arguments are therefore summarised below:

- in terms of the *efficient management of waste*:
  - the absence of a geological repository capable of receiving B&C waste does not allow ONDRAF/NIRAS to fulfil its public service mission and thus close its management system for this waste;
  - any unjustified delay in the implementation unnecessarily increases the costs of managing the storage facilities (controls and maintenance of facilities, possible repackaging or reconditioning of waste, etc.);
- in terms of applying the *"polluter pays" principle*:
  - without a geological repository effectively constructed and in operation, the real cost of disposal cannot accurately be established and passed on to producers by ONDRAF/NIRAS ; the more time passes, the more producers will have completed delivering waste to ONDRAF/NIRAS, therefore making it very difficult, even impractical, to pass on potential increases in the management costs via an increase in the estimated charges for the management of their waste: the adjustments could then have to be charged to the remaining producers and/or the Belgian State, and thus the citizen, which in both cases contravenes the "polluter pays" principle;
- in terms of *knowledge continuity*:
  - any delay in implementation makes it more difficult to maintain continuity in the national expertise and know-how, particularly in terms of knowledge of the waste and RD&D, but this continuity makes an essential contribution to the safety of the solution developed and its implementation;
- in terms of *intragenerational equity*:
  - any delay in implementation extends the situation of uncertainty for the municipalities on whose territory the waste is currently in interim storage, but for an undefined period;
- in terms of *intergenerational equity*:
  - any delay in implementation increases the burden of the management responsibility, including associated burdens, passed on to future generations.

The envisaged date for a geological disposal facility to begin operating, which is 2035–2040 at the earliest, must allow for continuation of the RD&D that still needs to be performed, and allows to maintain follow up of developments regarding management possibilities that were examined in the Waste Plan but were discarded (sections 7.2.1.2 and 7.2.2).

9 Develop and implement geological disposal within the scope of an integrated decision-making process

It was within the framework of a programme dedicated to the long-term management of category A waste that, in the mid-1990s, ONDRAF/NIRAS developed a vision, innovative at the time, with regard to the need for scientific, technical and societal aspects to be integrated, in a balanced way, in the development and implementation of radioactive waste disposal.

The participative working methodology and the integrated decision-making process developed within the scope of the programme relating to category A waste, which inspired various radioactive waste management programmes abroad, also gradually fuelled the thoughts about the B&C programme. Indeed, from 1974 until the mid-2000s, the work on the long-term management of B&C waste paid attention mainly to scientific and technical, as well as safety and environmental protection aspects, while largely ignoring the societal aspects, which made it impossible to establish societal support for the management solution being developed.

The importance of societal and ethical aspects in the long-term management of radioactive waste, taking account of the issues associated with this management, led ONDRAF/NIRAS to conclude to the need to implement an approach that integrated in a balanced way the four interdependent aspects for a sustainable long-term management solution, namely the environmental and safety, technical and scientific, financial and economic, and societal and ethical aspects (Inset 1 in section 1.2). ONDRAF/NIRAS deems such an approach essential, whatever the long-term management solution to be implemented.

The need to factor in explicitly the societal and ethical aspect in the long-term management of B&C waste and the need to include this aspect in a participative decision-making process were first put into perspective by ONDRAF/NIRAS in 2001 in the contextual document [18] of the SAFIR 2 report (section 8.1.1.2) and were repeated in the conclusions of the review of the SAFIR 2 report conducted under the auspices of the NEA. The NEA review report [10] in fact confirmed the importance of societal aspects and the need for the B&C programme to think about the structure of a decision-making process and, in particular, as to how and when to increase stakeholder involvement in this process, where the term "stakeholders" can be defined as meaning parties who have or show an interest in the project or process or those involved in the process. In 2005, the NEA explained its vision of the concept of the decision-making process in the context of radioactive waste management as follows [150]:

> *"In the new decision-making context it is clear that (a) any significant decisions regarding the long-term management of radioactive waste will be accompanied by a comprehensive public review with involvement of a diverse range of stakeholders; (b) the public, and especially the local public, are not willing to commit irreversibly to technical choices on which they have insufficient understanding and control; and (c) any management options will take decades to be developed and implemented, which will involve stakeholders who have not yet been born. Thus, a "decision" no longer means opting for, in one go and for all time, a complete package solution. Instead, a decision is one step in an overall, cautious process of examining and making choices that preserve the security and well-being of the present generation and the coming ones while not needlessly depriving the latter of their right of choice."*

Having received in 2004 from its supervisory authority, following the publication of the SAFIR 2 report and its international review, the task to assess the different possible strategies for the long-term management of B&C waste and plan a societal dialogue with all parties concerned (section 5.2.2), ONDRAF/NIRAS undertook various societal consultation initiatives in preparation for drawing up the Waste Plan and the supporting SEA in accordance with the provisions of the Law of 13 February 2006. These initiatives were the first step in an approach integrating the four aspects for a sustainable solution for the long-term management of B&C waste.

In the same vein, ONDRAF/NIRAS identified key elements in the decision-making process relating to the development and gradual implementation of the geological disposal solution that it recommends for the long-term management of B&C waste (section 9.1), which must be approved by a decision in principle. These key elements are, however, applicable whatever the management solution approved. ONDRAF/NIRAS then drafted a first outline of this process, planning the eventual local integration of the repository (section 9.2), where the concept of local integration complies with the provisions of the Law of 29 December 2010. Indeed, this law enables ONDRAF/NIRAS to take measures intended to create and maintain the necessary societal support to integrate a repository into a local community [6].

The outline of decision-making process drafted by ONDRAF/NIRAS, which formally begins with a decision in principle, is a basis for discussion that must be enhanced and refined, even modified, through dialogue with all stakeholders, which will start without delay and will help to begin to establish a participative process in the B&C programme (section 9.4). The decision-making process must in fact receive the support of all stakeholders in order to be implemented. This major task, which will begin by identifying the stakeholders, must make it possible to respond to the issues of who decides what, when, on what basis and using what methods. With the exception of the provisions of the Law of 13 February 2006, there is currently no normative system describing how to complete the different steps between a decision in principle on the long-term management of radioactive waste and the nuclear licence application needed to implement the chosen management solution. Identification of the key decisions to be made, the stakeholders taking part in the different steps of the decision-making process, the respective roles and responsibilities or even, for instance, the documentation to be prepared, all present a major challenge.

The decision-making process should be included in a new normative system, providing ONDRAF/NIRAS and all stakeholders with whom it will need to cooperate with a sufficiently stable and solid basis for their work to develop within a sufficiently well-defined framework (section 9.3).

9.1 Key elements in the decision-making process

In addition to having an integrated nature, ONDRAF/NIRAS wishes the decision-making process relating to the development and implementation of a geological disposal solution for the long-term management of B&C waste (chapter 8) to include the following key elements:

- progress in steps,
- be participative,
- be adaptable,
- be transparent and credible,
- ensure continuity, including knowledge continuity.

These key elements have been identified by ONDRAF/NIRAS from its experience of working in partnership with local communities within the scope of the category A disposal programme (Inset 7 in section 4.2.3 and Inset 17 in section 9.2.2), the recommendations of participants in the societal consultation initiatives that it launched in 2009–2010 regarding the long-term management of B&C waste (section 1.2) [30, 31], and best practices observed internationally. The practical translation of these key elements into the decision-making process and the normative system to be established will be subject to societal dialogue.

Best practices in terms of participative decision-making processes relating to radioactive waste management are found in the processes followed by the majority of foreign programmes for geological disposal, whether these are advanced programmes, like that of Canada for the long-term management of category A&B waste (Inset 10 at the end of section 5.2.3) [80], or programmes in the development or reorganisation phase, in which they are included as recommendations (for example [79, 81, 102, 151, 152]).

Best practices observed abroad have been described, analysed and summarised in several studies and/or within various international working groups (Inset 16), in particular

- the CARL project, which analysed the consequences of involving stakeholders in a decision-making process for radioactive waste management [153];
- the Forum on Stakeholder Confidence (FSC), created under the auspices of the NEA, which aims to facilitate the sharing of experiences in tackling the issue of the societal aspect in radioactive waste management, and which explores how to conduct an effective dialogue with the public in order to strengthen confidence in decision-making processes [150, 154, 155].

ONDRAF/NIRAS continues to monitor best practices abroad and the recommendations issued internationally, either directly or with its university partners.

Inset 16 – Best practices observed abroad in terms of participative decision-making processes for radioactive waste management

Principal lessons from the CARL project [153]. One must

- attach enough importance to the development of the participative processes and their facilitation, avoiding in particular reproducing "imported" participative models "as they are", insofar as each country is characterised by specific contextual variables (cultural, societal, technical or legal for example) likely to affect the participative processes;
- allocate sufficient financial and time resources to the participative processes and clearly define the period in which each stakeholder is involved and the extent of the involvement expected from them;
- pay enough attention to developing the knowledge and skills of stakeholders;
- guarantee transparency and adequate feedback to the stakeholders;
- ensure the correct representation of groups affected within the population;
- take into account the existence of multiple opinions about radioactive waste management within the population.

Principal lessons from the FSC study on the development and current practices in terms of partnerships in thirteen countries [155]. This study shows that in the past decade, significant changes have taken place in citizens' participation in resolving issues relating to radioactive waste management:

- development of the transfer of information to local communities and the consultation of local communities in a partnership approach, in other words development from a symbolic involvement to a real influence for citizens;
- development of the role of local communities from passive to active;
- development of a wide range of administrative formats for the collaboration;
- recognition of the need and legitimacy of measures giving a certain amount of power to the community and socio-economic benefits;
- the emergence of new ideals and new foundations for the collaboration, especially shared learning, the contribution of added value to the community and/or host region and sustainable development.

9.1.1 Progress in steps

Just like many organisations responsible for radioactive waste management abroad, ONDRAF/NIRAS has opted for the stepwise development and implementation of the geological disposal solution that it recommends. Before a repository takes its definitive form, after the emplacement of all waste and closure of all the disposal galleries and all access galleries and shafts, a series of steps must be completed and a series of decisions made that would extend over a period of around one hundred years from the decision in principle to the complete closure of the repository.

In practical terms, the journey towards the ultimate objective of the complete closure of the repository, at the end of its operation and any period of *in situ* controls, is broken down into a series of steps, each aimed at achieving an intermediate objective (Figure 44). Each step on this journey will be completed by a decision called a "key decision" relating to this intermediate objective, which will be made by one or more of the competent authorities based on arguments supported by the level of knowledge in terms of safety, environmental protection and feasibility, as well as on considerations relating to the concerns and requirements arising from society, or more generally based on an integrated approach of all the constitutive elements of a sustainable management solution. This decision may take various forms, for example the choice of a disposal site or a licence granted by FANC within the scope of the construction, operation or closure of the repository (section 9.2). Each new step will begin with an evaluation of the programme and the next intermediate objective depending on the key decision that has completed the previous step.

The stepwise nature of the decision-making process allows to take into account evolutions (scientific, technical, societal, regulatory, etc.) likely to take place during the development and implementation of the geological disposal solution (section 9.1.3).

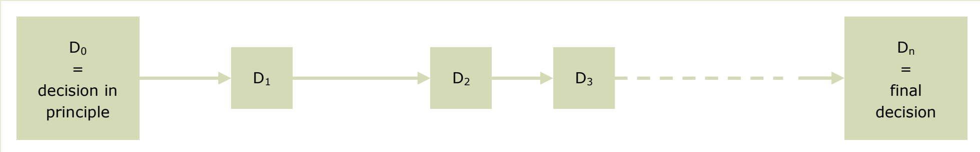


Figure 44 – Stepwise decision-making process. The journey towards the ultimate objective of the process is broken down into a series of steps, each aimed at achieving an intermediate objective and which will be completed by decisions called "key decisions".

9.1.2 Be participative

Given the societal issues in the long-term management of radioactive waste, the decision-making process must be participative, i.e. give all stakeholders a voice on this issue, where the term "stakeholders" can be defined as meaning parties who have or show an interest in the project or process or those involved in the process. In particular, it therefore means waste producers, safety and environmental protection authorities, local, provincial and regional authorities, local communities, the general public, the scientific world, professional organisations, non-governmental organisations, ONDRAF/NIRAS and, if the project is likely to have non-negligible transboundary environmental impacts, foreign parties. As for the participation, this can take different forms depending on the objective, as is for example the case with the local partnerships that ONDRAF/NIRAS has established within the scope of the programme for the long-term management of category A waste (Inset 7 in section 4.2.3).

Each step in the decision-making process, which will be completed by a key decision made by one or more competent authorities, will itself be divided into several sub-steps (Figure 45). During each sub-step, the stakeholders will familiarise themselves with the subject being considered within a participative framework and will form an opinion, which will lead to a conclusion and an intermediate decision, constituting one of the bases that the competent authority(ies) will use to make the required key decision.

A participative decision-making process has notably been defined as being a "*way of developing a policy, according to which an authority involves citizens and societal organisations, companies and/or other authorities at as early a stage as possible so that it can prepare, define, implement and/or assess the policy with them, using an openly interactive and/or collaborative method*" [translation ONDRAF/NIRAS] [156]. A participative decision-making process therefore provides a forum for stakeholders so that they can establish their own definition of the problem and develop their view of the solution. In this respect, the societal consultation organised on the initiative of ONDRAF/NIRAS and the public consultation organised as part of the legal consultation procedure required by the Law of 13 February 2006 are the beginnings of a participative decision-making process (section 1.2).

In practice, the stakeholders and type of participative process will vary depending on the step of the process under consideration, and even depending on the sub-step of the current step. Thus, making a decision in principle is the responsibility of the Government, the identification of potential disposal sites should notably involve representatives from the local communities concerned, and FANC and the competent environmental protection authorities will be responsible, within the scope of the licence application procedure for the geological repository, to give an opinion on the degree of safety and protection provided by the disposal system and to authorise its implementation (see also section 9.3).

Some replacement of the people involved will be needed to ensure continuity in the decision-making process, due to its very long duration.

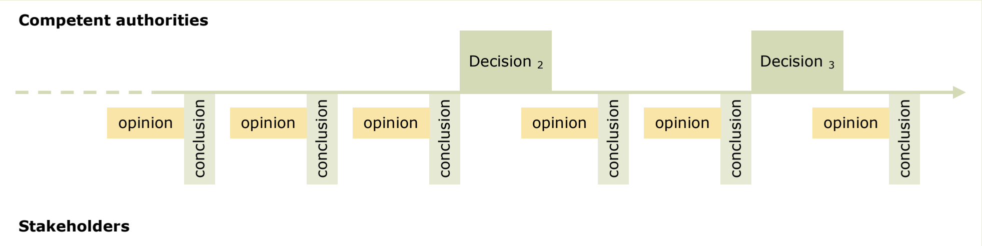


Figure 45 – Stepwise and participative decision-making process. During each sub-step, the stakeholders will form an opinion, leading to a conclusion and an intermediate decision, which will constitute one of the bases that the competent authorities will use to make the required key decision.

As the organisation responsible for managing radioactive waste in Belgium, ONDRAF/NIRAS can legitimately launch a process leading to the implementation of a geological disposal facility. Nevertheless, ONDRAF/NIRAS considers that since it is one of the key parties, it is not best placed to organise or support participative processes. Consequently, it wishes to assign the organisation and support for these processes to specialists. It believes that monitoring by an institutionally guaranteed, independent supporting body offers the best guarantee for the proper functioning of the participative processes.

According to independent analyses of the societal consultation organised by ONDRAF/NIRAS in preparation for drawing up the Waste Plan and SEA [157, 158], public participation cannot in fact be limited to consultations planned within the scope of the existing legal procedure for the environmental impact assessment, and it would be better if ONDRAF/NIRAS did not directly control the participative processes to be implemented.

9.1.3 Be adaptable

Given that the decision-making process, from making a decision in principle for a geological disposal solution to the complete closure of the repository, will extend over a period of approximately one hundred years, it must be adaptable. Indeed, it must be able to take into account scientific and technical evolution, the results of safety and environmental impact assessments, cost control requirements and societal, legal and regulatory changes, while retaining its momentum (Figure 46). These evolutions could lead to the revision of certain conditions relating to the repository's implementation.

The decision-making process must also be adaptable so as to allow previous decisions to be modified. This is the *adaptability* of the decision-making process, sometimes called the "reversibility" [159] or "flexibility" of the decision-making process in other countries. However, the decision in principle would only be reviewed in the case of a major event (for example a drastic amendment in the regulatory or international context) or a prohibitive safety or feasibility problem.

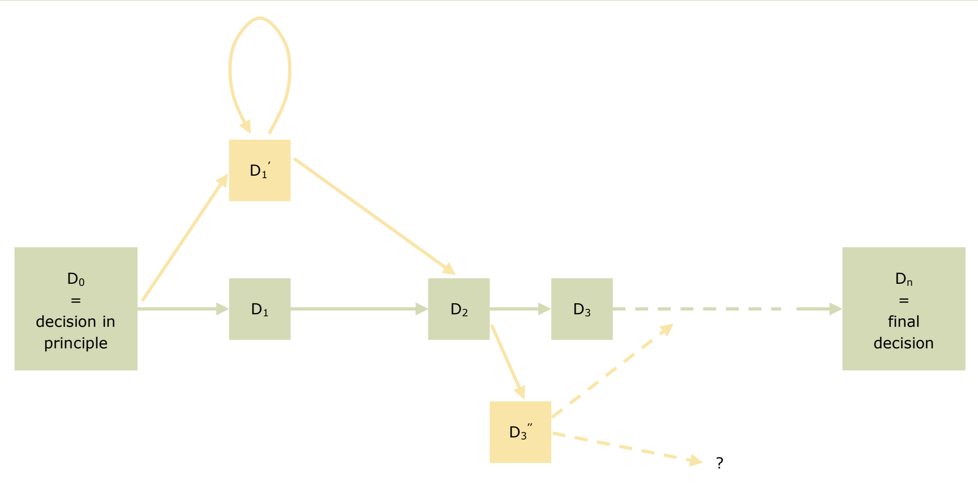


Figure 46 – Stepwise and adaptable decision-making process. Each key decision may represent a deviation from the reference decision-making process (in green), including resulting in more detailed work on the current step. In orange is an example of a decision-making process that deviates from the reference decision-making process. However, only a major event (for example a drastic amendment in the regulatory or international context) or a prohibitive safety or feasibility problem could result in going back on the decision in principle.

In practice, growing importance is attached internationally to considering the adaptability of the decision-making process and the retrievability of waste during repository development and disposal planning (see also section 8.1.3.1). The reasons for such requirements are both technical and societal in nature (see for example [136, 137, 138]). In particular, these are as follows.

- Providing for adaptability throughout the decision-making process allows the cautious progression towards the implementation of a solution that can become definitive for radioactive waste management.

- All operations on waste containers must be able to be reversed (using identical or similar means to those used for their installation) during the disposal phase for the waste, so as to avoid an irreversible situation in the case of incident or accident.
- Future generations must be able to make the most of the technical and scientific advances of future decades that can be used to improve the geological disposal solution (waste conditioning techniques, disposal techniques, etc.).
- Future generations may want to be able to retrieve irradiated fuel that has been disposed of in order to extract and recycle the fissile materials that are still contained within such fuel.

A stepwise and adaptable approach [151] means in particular that each new step in the decision-making process begins with an analysis of the implications of the key decision that completed the previous step, considering the targeted decision, followed by the definition of a framework suited to this new step and the next key decision to be made: identification of the stakeholders to be involved during the new step and definition of their respective roles and responsibilities, definition of the consultation and participation methods or even, for example, the expected duration of the step, all taking account of the context (societal, scientific and technical, regulatory, etc.) within which the step in question is taking place.

9.1.4 Be transparent and credible

Transparency and credibility of the decision-making process will be important for establishing and maintaining the desired societal support for the geological disposal solution. Therefore, ONDRAF/NIRAS will endeavour to implement the following approaches in particular.

- The process itself will have to be fully documented (roles and responsibilities of the stakeholders, role of the independent monitoring body, successive steps in the process, etc.).
- The key data and methodologies used will be submitted to the stakeholders (authorities, experts, public, etc.) throughout the decision-making process and discussed in detail with them. The current effort to make the information clear, comprehensible and accessible will be intensified.
- The scientific and technical knowledge will regularly and systematically be submitted for peer review [31, 151, 157].
- The arguments that underpin all the decisions made will have to be subject to independent monitoring.

9.1.5 Ensure continuity, including knowledge continuity

Given the duration of the decision-making process, its continuity will be essential, both for establishing and maintaining societal support for the geological disposal solution and for developing and implementing this solution. ONDRAF/NIRAS will encourage this continuity, which is one of the pillars of its B&C programme.

In particular, the continuity of the decision-making process will require

- the continuity of the participative processes. Interactions with society will therefore have to be recurrent, and it would be better if they were firmly established institutionally;
- the management and transfer of information and knowledge, including all the decisions made and the reasons (arguments) for which they have been made. The whole process and the elements making it possible to move from one step to the next must be clearly documented, traceable and accessible.

Some replacement of the people involved will be needed to ensure continuity in the decision-making process, due to its very long duration.

9.2 Outline of reference decision-making process supporting the gradual implementation of the recommended solution

The outline of decision-making process drafted by ONDRAF/NIRAS *assumes that the decision in principle that would mark the formal start of the decision-making process will confirm geological disposal in poorly indurated clay (Boom Clay or Ypresian Clays) as an institutional policy for the long-term management of B&C waste.* This outline is based at the level of key decisions made by the competent authorities at federal level (Federal Government, the supervisory authority of ONDRAF/NIRAS, FANC, etc.), regional level (environmental protection authorities, regional Government(s), etc.) or local level (municipalities) at the end of successive work steps. It depends on the current maturity of the system and, being based on the factors presently known by ONDRAF/NIRAS, it is mainly technical and scientific at this stage. It is principally based on decision-making requirements with regard to

- continuing RD&D, including establishing priorities;
- gradually selecting one or several potential sites for implementing geological disposal;
- radiological safety and environmental impact assessment;
- preparing the various licence applications to be submitted to the competent authorities;
- phasing of disposal operations.

The current outline of decision-making process is a basis for discussion that must be enhanced and refined, even modified, through dialogue with all stakeholders that will start shortly (section 9.4). The decision-making process must indeed receive the support of all stakeholders in order to be implemented. It will be further refined as the B&C programme develops, particularly during the evaluation to be made at the beginning of each new step, according, among other things, to the key decision that completed the previous step and changes that could have taken place in the regulatory framework (section 9.1.3).

The outline of decision-making process associates with the majority of key decisions one or several reports relating to the safety and feasibility of the disposal solution being developed, as well as its environmental impact (Figure 47). Other documents will accompany the development and implementation of the disposal solution, especially the RD&D programme that ONDRAF/NIRAS intends to publish periodically and which will support interactions with stakeholders in particular (section 8.1.6).

- The *key decisions* to be requested of the competent authorities, leading to the implementation of a geological disposal facility for B&C waste in poorly indurated clay, define a series of steps in the B&C programme. They are relatively independent of its exact development. They have been identified as follows:
  - obtaining the green light for the launch of the siting process, i.e. the process that must gradually lead to the identification of one or several potential disposal sites, within one or several favourable geological areas, and ultimately to the confirmation of the choice of a single disposal site through the granting of the nuclear licence for construction and operation for the facility developed, and the other permits required. Whatever the results of the siting process, they are dependent on a favourable assessment of the solution proposed by the safety and environmental protection authorities within the scope of the licence application procedure for geological disposal (section 9.2.1);
  - obtaining the green light for the development of one or more preliminary integrated disposal projects within a participative framework (section 9.2.2);
  - choosing the future disposal site and obtaining the green light to proceed to the project phase (section 9.2.3);
  - the granting of the licences and permits required to begin the construction phase (section 9.2.4);
  - the granting of the acceptance report and subsequent licences (section 9.2.5).

  Each decision-making step will also be used to refine the cost assessment of disposal, and therefore the tariffs for taking charge of the waste by ONDRAF/NIRAS, and hence apply the "polluter pays" principle on a firmer basis.

- Each key decision will be requested on the basis of one or several *reports* formally submitted to the authority(ies) responsible for the decision. These reports will be, in particular, integrated supports such as *safety and feasibility cases* (SFCs), in accordance with international practice and recommendations [150, 160], coupled with environmental impact assessment (EIA) of the disposal system at the development stage reached. At the start of each step, the nature and objective, and therefore the degree of detail, of the reports to be prepared, will be re-evaluated according to the key decision made at the end of the previous step and the programme's scientific, technical and societal maturity. These documents will increasingly focus on a particular site.

An indicative development and implementation schedule for geological disposal, assuming disposal in Boom Clay and considering the minimum estimated periods for the different steps in the decision-making process from a scientific and technical perspective, would lead to the disposal of category B waste from 2035–2040 and the disposal of category C waste (heat-emitting waste) from 2080, given the need to allow this waste to cool at the surface for a minimum of 60 years in order to avoid undue perturbations in the host formation. These dates have been derived on a purely technical basis and do not take into consideration the time needed for the participative processes. In fact, it is impossible to predict the time needed for societal stakeholders to familiarise themselves with complex technical cases with multiple issues, get of sense of ownership of the cases within the scope of a participative process, and make their mark on them.

The indicative schedule for disposal in Boom Clay is likely to have to be extended, for example

- if the study of Ypresian Clays is retained for the siting;

- if Boom Clay is abandoned and studies then have to focus solely on Ypresian Clays. In this case, the disposal of category B waste would be delayed by at least ten years. Indeed, less is known about Ypresian Clays than Boom Clay and this difference cannot be entirely reduced by an increase, even substantial, in research resources.

In all likelihood, it will be around a hundred years between beginning the construction of the repository and its complete closure.

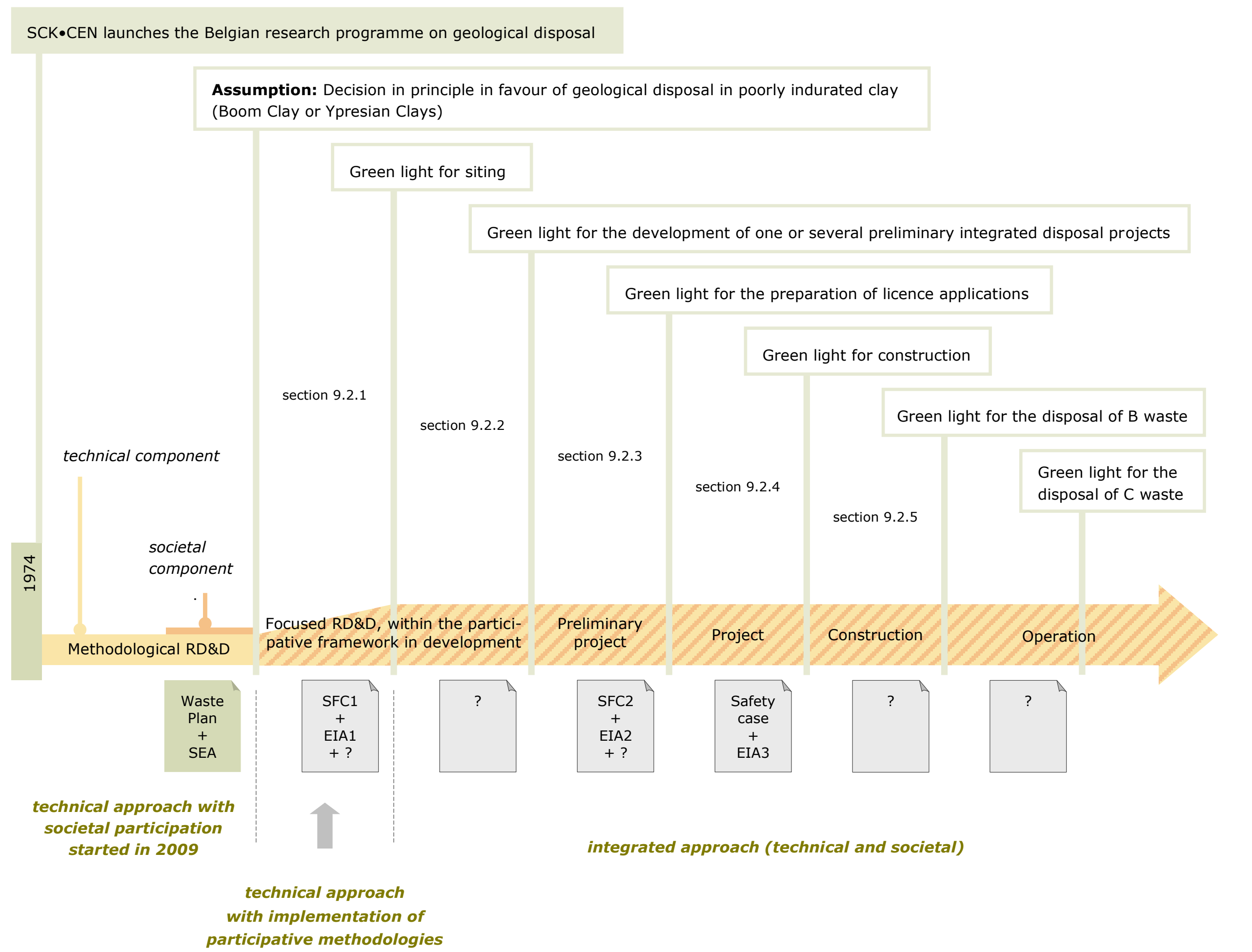


Figure 47 – Outline of decision-making process for the development and implementation of a solution for the long-term management of B&C waste, assuming that geological disposal in poorly indurated clay is confirmed by the Government. This process is similar to the decision-making process followed in the context of the long-term management of category A waste (section 4.2.3). It must be enhanced and refined, even modified, through dialogue with all stakeholders, and the recently introduced societal and ethical aspect must gradually take on a place of its own, in the same way as the other three constitutive aspects for a sustainable management solution.

Insofar as the decision-making process is likely to be delayed if stakeholders do not have an accurate enough idea of the quantities and types of waste in question, various decisions that influence these quantities, but which are not a matter solely for ONDRAF/NIRAS, will also have to be made in a timely manner (section 10.2).

9.2.1 Obtaining a green light to launch the siting process

If the Government confirms the solution recommended by ONDRAF/NIRAS as an institutional policy for the long-term management of B&C waste, ONDRAF/NIRAS will prepare a first safety and feasibility case (SFC1) intended to ask the competent authorities for the green light to launch the siting process.

The siting process is a stepwise process that includes in particular,

- for selected potential host formation(s), the identification of regional expanses where, considering present knowledge, it is reasonable to think that the feasibility and safety of a repository could be confirmed; if these formations are poorly indurated clay formations, the areas of Belgian territory likely to be taken into account for a repository will be situated in the north-east and the northernmost part of western Belgium;
- the identification of any additional applicable conditions or limitations, such as restrictions in the choice of sites related to the protection of exploitable natural resources, especially aquifers, the presence of protected areas or the presence of subsoil areas dedicated to specific uses (for example the potential underground storage of CO_2), or even restrictions related to the implications of other plans and programmes in Belgium;
- the potential choice of a reference host formation;
- the call for applications from local communities potentially interested in a dialogue with ONDRAF/NIRAS on the issue of possibly implementing a geological repository on their territory.

The SFC1 will concentrate on assessing the safety and feasibility of a repository within one or several defined zones in Boom Clay and within one or several defined zones in Ypresian Clays. The section on Boom Clay will contain a detailed analysis of the possibility of transferring the knowledge acquired in the HADES underground laboratory to one or several more extended zones of Boom Clay. The section on Ypresian Clays will be less detailed than that on Boom Clay. It will focus on a detailed and systematic study of the possibility of transferring the knowledge acquired about geological disposal in Boom Clay to Ypresian Clays, given the knowledge on Ypresian Clays acquired within the scope of RD&D dedicated to these clays. This study will be complemented by a preliminary safety assessment. The SFC1 will include environmental aspects (EIA1), including, if necessary, transboundary aspects, and will provide responses to societal concerns.

The responsibilities relating to the decisions required on the basis of the SFCs must be clarified in the normative system to be implemented (section 9.3).

9.2.2 Obtaining a green light for the development of one or more preliminary integrated disposal projects

The development of one or more preliminary integrated disposal projects within a participative framework means integrating the preliminary disposal project into a wider project offering economic and societal added value at local and regional levels. This approach is similar to the one followed within the scope of the category A disposal programme (Inset 7 in section 4.2.3), but must be adapted to the B&C programme. The (preliminary) integrated projects approach also complies with the provisions of the Law of 29 December 2010, which allows ONDRAF/NIRAS to take measures intended to create and maintain the necessary societal support to ensure the integration of a repository in a local community (Inset 2 in section 2.1).

Various important lessons have been highlighted within the scope of the category A disposal programme, which focus not only on the preliminary project phase, where different local partnerships have analysed the possibility of potentially accepting a repository on their territory and the associated conditions, but also on the project phase, where the integrated disposal project chosen by the Government has been and continues to be developed in close collaboration with the local communities (Inset 17).

The type of document used to support the green light for the development of one or more preliminary integrated disposal projects must be determined, along with the responsibilities related to the decisions on the subject.

Inset 17 – Principal lessons from the Belgian experience in terms of local partnerships [161, 162]

These lessons can be summarised as follows.

- The choice of an institutional policy for long-term management is the first milestone in the decision-making process that must accompany the development and gradual implementation of the type of long-term management solution chosen.
- The chosen long-term management solution must be considered as being part of a multi-dimensional project offering added value for the region in which it will be implemented.
- The assessment and study of the possibility of accepting the chosen management solution on their own territory, including the definition of the associated conditions, must be conducted on a voluntary basis.
- The stakeholders involved in the different steps of the decision-making process must be representative of the social, political and economic organisations most directly affected by the current step.
- The framework and organisation of the work must give enough independence to the participative structure to enable it to make its mark on the project.
- Local stakeholders must take ownership of the project through the co-design and co-development of an integrated project that creates added value for the region.
- The investment in time and energy expected from all stakeholders involved in a participative decision-making process is considerable.
- The decision-making process must be adaptable and remain so, and in particular, at each step, provide for the identification of the stakeholders to be involved, a clear definition of their roles and responsibilities, especially taking into account the decision(s) targeted by the step in question, and the working methodology used to be adapted to the specific nature of the current step.
- The municipalities located close to a site that has been chosen for a repository must be sufficiently involved in the further development of the integrated project and in due time.
- The conclusions and decisions made during the decision-making process must be documented and well-argued.

9.2.3 Choosing the future disposal site and obtaining the green light to proceed to the project phase

Having obtained the green light needed to begin the siting process and implement suitable participative structures, ONDRAF/NIRAS will continue the RD&D so as to prepare for the choice, by the competent authorities, of the site of the future repository and the green light to proceed to the project phase. The project phase involves the detailed studies needed to be able to compose, then submit the licence and permit application files required to begin the repository construction phase.

There are several possible siting approaches for repositories. An analysis of experiments conducted in Belgium and abroad can draw some general lessons (Inset 18).

Inset 18 – General lessons from siting experiments conducted in Belgium and abroad

These lessons can be summarised as follows.

- The societal approach relating to local acceptance of the construction of a repository cannot be separated from the decision-making process as a whole. The siting process is at the intersection of the societal and ethical, technical and scientific, environmental and safety, and financial and economic aspects.
- An approach that aims to identify the best possible disposal site on the basis of strictly scientific or technical selection criteria often leads to a standstill, as ONDRAF/NIRAS found to its cost at the beginning of the 1990s, when preselecting sites for the surface disposal of category A waste [163]. The search for a suitable site, both in terms of safety and feasibility and in terms of societal acceptance, therefore takes precedence over the search for the "best" site.
- An approach based on a voluntary arrangement with one or several local communities must — in the case of geological disposal — be coupled with the preselection of one or several geological formations and extensive regional zones where the safety and feasibility of a repository could, *in principle*, be guaranteed.
- The approach followed must allow societal and technical aspects in the broad sense to develop in parallel. Indeed, whatever the participative process selected, it must always involve a series of scientific and technical steps for the gradual confirmation of the quality of the site(s) under consideration and the suitability of the repository design(s) to this (these) site(s) as well as to assess the safety of the disposal system [113].
- Communities already used to the presence of nuclear activities (in the broadest sense) on their territory are often more inclined to consider the construction of a repository in a positive and pragmatic way [153].
- Society is involved principally at local or supra-local level. The momentum of participation is more difficult to establish and maintain at higher levels.
- The desire to involve local communities requires providing them with a structure and resources allowing them to participate in the decision-making process and the technical developments in an independent, appropriate and critical way.
- A clear decision-making framework must be established from the start of the siting process. The granting of a right to veto to local communities is often a *prerequisite* condition.
- Disposal projects are frequently integrated into a broader framework offering local or supra-local, economic and societal added value.
- Whatever the results of the siting process, they are dependent on a favourable evaluation of the solution proposed by the safety and environmental protection authorities.

A second safety and feasibility case (SFC2) will provide the competent authorities with all the necessary scientific and technical elements to enable them to choose, in full knowledge of the facts, the site for the future repository, along with a preliminary integrated disposal project, potentially from among several variations, adapted to this site. In particular, it will incorporate the final results from the PRACLAY heater test. It will be based on an environmental impact assessment (EIA2) of the disposal solution developed for the site(s) under consideration, including any transboundary impacts, and will provide responses to societal concerns.

9.2.4 The granting of the licences and permits required to begin the construction phase

Once the future disposal site and a preliminary disposal project suited to this site have been selected, ONDRAF/NIRAS will conduct detailed studies of the disposal system and prepare, in dialogue with the stakeholders, the application for the nuclear licence for construction and operation of the repository, along with the applications for conventional licences and permits.

In accordance with the system established by FANC [140], the submission of the application for the licence for construction and operation should be supported by a *safety case*, including a safety report and an environmental impact assessment of the planned facility on the chosen site (EIA3, at project level), with any implementation variations, including a physical protection plan and a safeguards analysis. The granting of the various licences and permits acts as confirmation of the choice of disposal site.

The period needed to conduct detailed studies of the disposal system and prepare the licence and permit applications and then to obtain them is estimated to be at least five years.

9.2.5 The granting of the acceptance reports and subsequent licences

The various acceptance reports and licences necessary for the operational and post-closure period of the repository will be requested and, in principle, granted in accordance with the system established by FANC [140]. These acceptance reports and licences will be based on successive revisions of the safety case for the repository throughout its lifespan.

The operational period, which includes the construction, operation and closure phases, would cover at least one hundred years.

- The construction period of the repository, after the construction and operation licence has been obtained, is estimated at 15 years.
- The waste would be disposed of in three groups:
  - category B waste from existing nuclear liabilities would be disposed of from 2035–2040 (at the earliest);
  - other category B waste would be disposed of from 2050 (at the earliest);
  - category C waste, which requires a cooling period of at least 60 years in surface storage, would be disposed of from 2080 (at the earliest).
- The rate at which the repository is completely closed in order to put it into a totally passive state, i.e. in such a state that it protects man and the environment without

requiring human intervention, will have to be established by future generations. Continually postponing complete closure indeed entails a risk that the facility will not be closed and will be abandoned, for example in the event that the management is interrupted due to unforeseen changes in society.

The controls that will be implemented in addition to the regulatory controls will be maintained after closure for a period to be agreed with the stakeholders, in particular in order to minimise the risk of human intrusion. It will be up to each generation to decide the knowledge and resources that it wants to transfer to the next generation to enable it to maintain these controls.

9.3 Development of a normative system

Given that the decision-making process for the development and implementation of geological disposal will extend over a significant period, it is advisable for it to be included in a normative system — currently lacking — that allows ONDRAF/NIRAS to have a sufficiently stable and solid basis for these works. (The lack of a normative system to support the implementation of the Waste Plan does not however mean the absence of a legal and regulatory framework for radioactive waste management activities such as they are currently performed — see section 4.1).

The normative system should be clearly defined and transparent with regard to all stakeholders, including the countries bordering Belgium that would have to be involved in a transboundary environmental impact assessment of the repository during subsequent work phases. It should specify, at least in outline, who will decide what, when, on what basis and using what methods. It could then fill the legal void that currently exists between, on the one hand, the provisions of the Law of 13 February 2006 relating to the assessment of the environmental impact of certain plans and programmes and public participation in their drafting, and, on the other hand, the existing nuclear licence system, the application of which only begins with the first nuclear licence application. In particular, the connections between the different decision-making levels (federal, regional, provincial and local) for the siting process and their respective responsibilities will require specific attention. The normative system should also provide for the creation of an independent monitoring body guaranteeing the proper functioning of the participative processes and the transparency of the decision-making processes with regard to all stakeholders.

In the most advanced countries in terms of the long-term management of B&C waste, such as Finland, France, Sweden and Switzerland, the policy relating to this management and its gradual implementation, as well as, in many cases, the follow-up of this implementation, have been sanctioned by one or several legislative acts (Inset 10 at the end of section 5.2.3). ONDRAF/NIRAS considers that Belgium has to bring itself into line with the practices in these advanced countries.

9.4 Making a participative process an integral part of the B&C programme

ONDRAF/NIRAS intends to make a special effort without delay to further develop and make a participative process an integral part of the B&C programme. First, ONDRAF/NIRAS will develop the necessary initiatives for this purpose with university research teams and various experts in order to outline the decision-making process to be followed and the stakeholders to be involved using a participative method.

The participative process, and the mechanisms that underpin it, will have to support the development then the implementation of the geological disposal system for the entire period, which is over several decades. This process began with the ONDRAF/NIRAS dialogues (discussions with interested citizens), the interdisciplinary conference (discussions with experts of various disciplines), and the citizens conference organised by the King Baudouin Foundation (work by a group of citizens, representative of the diversity of civil society) (section 1.2). Its more advanced development may be inspired by lessons learned from national and international projects and studies in terms of societal involvement in issues relating to radioactive waste management (Inset 17 and Inset 18 in section 9.2 and Inset 16 in section 9.1).

In practice, making a participative process an integral part of the B&C programme will take several years, which will mainly be devoted to the following objectives:

- refine and improve the existing outline of decision-making process (section 9.2), and in particular the siting process, through dialogue with all stakeholders, so as to integrate the societal and technical milestones in a balanced way (section 9.1); this work will focus on
  - the phasing, by identifying additional technical and/or societal decision-making steps;
  - the necessary reports, with the identification of additional technical and/or societal documentary milestones;
  - the stakeholders, with the identification of the stakeholders to be involved during the successive steps of the process;
  - the methodologies for the participative work;
  - the methodologies for the siting;
- implement participative working methodologies intended to help stakeholders familiarise themselves with the different aspects of the long-term management of B&C waste, then get a sense of ownership of the case;
- specify, within a participative framework, the requirements for the retrievability of disposed waste, control of the proper functioning of the disposal system, and knowledge transfer relating to the repository (including institutional memory of its location) and the waste it contains;
- establish interaction methods with the stakeholders about such technical documents of ONDRAF/NIRAS as SFCs and RD&D programmes.

Once firmly established as part of the B&C programme, the participative process will carry on throughout the decision-making process so as to encourage the desired societal support to be maintained.

3

Part 3

Related issues the answers to which are not a matter solely for ONDRAF/NIRAS

10 Related issues likely to impact the management system of ONDRAF/NIRAS, and in particular the long-term management of B&C waste

Various related issues have been identified by ONDRAF/NIRAS as being likely to impact its radioactive waste management system, and in particular the long-term management of B&C waste and its financing. These issues, the answers to which are not a matter solely for ONDRAF/NIRAS, focus on aspects of the legal and regulatory framework (section 10.1) and on certain aspects of the technical inventory of the conditioned waste to be considered (section 10.2). However,

- they do not call into question the need for a decision in principle as soon as possible for the long-term management of B&C waste;
- they do not call into question the possibility of making this decision, which the SEA Advisory Committee confirmed in its opinion on the draft Waste Plan and the SEA [33]: *"It would have been useful to establish a summary in the Waste Plan […] of the impact of these uncertainties on waste volumes, and then establish the impact of these variations on the descriptive data for the considered management solutions […]. This data is the key to a justified assessment of the environmental impact […]. Nevertheless, at this stage, its absence does not call into question the information intended for a decision in principle."* [translation ONDRAF/NIRAS];
- they do not call into question the recommended solution of ONDRAF/NIRAS for the long-term management of B&C waste.

These issues are important for the development of a geological disposal solution (if this solution is approved by a decision in principle) and the decision-making process that must accompany it. Answers should be provided in the coming years, at institutional level or by the owners or holders of the materials in question, depending on the case.

10.1 Legal and regulatory framework for long-term management

In order to develop and optimise, then implement, in full knowledge of the facts, a geological disposal solution for the long-term management of B&C waste, ONDRAF/NIRAS will need a sufficiently clear and comprehensive applicable legal and regulatory framework.

In particular, the legal framework specific to geological disposal must specify

- the licence application procedure, and especially
  - the role of the various institutional bodies at different levels (federal, regional, provincial, local, etc.),
  - the complementary nature of the various licences (environmental permits, nuclear licence, etc.),
  - specific requirements, such as the specific role of the host formation, the method for assessing the protection of man and the environment in the very long term (over tens of millennia and more), the protection of natural resources, including water, and even the role, in terms of safety, of the controls carried out after the closure of the repository;
- the application of international requirements in terms of safeguards in the specific case of disposal of B&C waste after the facility is closed.

These regulatory aspects are mainly FANC's responsibility, but also involve other institutional bodies, particularly on a regional level. Many developments in the subject have recently emerged within the scope of the project for the surface disposal of category A waste. Thus, FANC is currently working

- on completing the regulations on radiation protection and nuclear safety applicable to repositories for category A waste and for category B&C waste;
- on standardising, in collaboration with the competent regional authorities for the environment,
  - the application procedures for nuclear licences and environmental permits,
  - the content of the corresponding licence application file.

The application of international requirements to geological disposal in terms of safeguards, which aim to prevent the diversion of fissile materials and their use for non-peaceful purposes, is currently the subject of international discussions (Euratom and IAEA). The corresponding requirements must be reflected in the Belgian regulations once they have been established internationally.

10.2 Potential modifications identified in the technical inventory of conditioned waste

The related issues identified by ONDRAF/NIRAS as being likely to affect the technical inventory of conditioned category B and C waste (section 4.3) do not call into question the geological disposal solution recommended by ONDRAF/NIRAS for the long-term management of B&C waste. They must however be clarified for several reasons:

- to encourage confidence and transparency between the different stakeholders (general public, ONDRAF/NIRAS, safety authority, radioactive waste producers, Federal Government, regional Governments, municipal authorities, etc.) by allowing them to know "exactly what waste is under discussion". This is especially important for the subsequent success of the process to choose a site for the geological repository in dialogue with local and/or regional authorities and stakeholders (population) and prepare the necessary licence and permit applications;

- to adapt the RD&D to take into account the specific nature of possible additional waste;
- to enable the design of the geological repository to be specified and optimised, including in terms of its dimensions;
- to enable as soon as possible any necessary adjustments in the tariffs for taking charge of radioactive waste by ONDRAF/NIRAS, given that these adjustments do not have a retroactive effect.

The related issues identified as being likely to affect the technical inventory of conditioned category B and C waste can be divided into five groups:

- the status of irradiated fuel and reprocessing;
- Belgium's future policy in terms of electricity production;
- a possible transfer of waste from category A to category B (and even a transfer in the other direction);
- the status of enriched fissile materials and plutonium-bearing materials;
- possible modifications to the inventory of category B radium-bearing waste.

10.2.1 Status of irradiated fuel and reprocessing

ONDRAF/NIRAS does not know the form of the waste from the back-end of the nuclear fuel cycle that it will have to take charge of: will it be non-reprocessed irradiated fuel or reprocessing waste? In accordance with the resolution of the Chamber of 22 December 1993 [40], which led to a suspension of the reprocessing of irradiated fuel from nuclear power plants, confirmed by the Council of Ministers on 4 December 1998, ONDRAF/NIRAS must in fact give equal consideration to the study of the geological disposal of reprocessing waste and that of non-reprocessed irradiated fuel. It therefore considers both scenarios for the RD&D and in its technical inventory for radioactive waste (see Inset 3 in section 3.2.1.2 for an introduction to the concepts of reprocessing and non-reprocessing).

This issue can be broken down into two sub-issues, discussed in outline below.

What is the future for irradiated fuel?

The decision of the Council of Ministers in 1998 was accompanied by a request to the organisations concerned to take the necessary steps to provide a more comprehensive and detailed view of the back-end of the nuclear fuel cycle. That concerning ONDRAF/NIRAS in particular said:

> *"with regard to final disposal, it is necessary to await the finalisation of the feasibility studies, optimisation of the concepts from the technical and economic perspective, and increased confidence in the safety studies;"* [translation ONDRAF/NIRAS]

ONDRAF/NIRAS provided response elements in 2001 in the SAFIR 2 report [16, 17] and will cover them in more detail in the safety and feasibility case 1 (SFC1) (section 9.2).

What will be Synatom's position regarding the status of its fuel?

Currently, Synatom, the owner of the irradiated fuel from the Doel and Tihange nuclear power plants, does not consider this fuel as waste and does not therefore ask ONDRAF/NIRAS to take charge of it.

It is unreasonable to consider foreign reprocessing of irradiated fuel without the resulting waste returning to Belgium. (Such a scenario would contravene the provisions of the Joint Convention [8], in particular.) Consequently, several scenarios may occur in the future for ONDRAF/NIRAS.

- ONDRAF/NIRAS is called on to take charge of reprocessing waste only. This is the situation where Synatom decides and has the authorisation to have all its irradiated fuel reprocessed, including MOX irradiated fuel.
- ONDRAF/NIRAS is called on to take charge of the non-reprocessed irradiated fuel (UO_2 and MOX) of Synatom and some existing reprocessing waste that is still to return from France. This is the situation where a definitive term is put on reprocessing and where Synatom declares all its irradiated fuel as waste to ONDRAF/NIRAS.
- ONDRAF/NIRAS is called on to take charge of existing and future reprocessing waste and non-reprocessed irradiated fuel (UO_2 and/or MOX). This is the situation where Synatom would decide to have only part of its irradiated fuel reprocessed and would receive the authorisation to do so, and would declare its remaining irradiated fuel as waste.

Furthermore, a series of additional technical considerations will have to be taken into account, particularly

- the gradual reduction during storage in the amount of fissile plutonium present in irradiated fuel;
- the international recommendation, within the framework of the safeguards, to impose, for the production of plutonium through reprocessing, defined objectives for the short-term reuse of this plutonium;
- the proportion of MOX fuel that could be reprocessed;
- the increase in the burnup of fuel;
- whether or not the latest reactor cores are to be reprocessed.

This means that ONDRAF/NIRAS could have to take charge of a potentially very wide range of category C waste, and especially irradiated fuel (UO_2 and MOX fuel with variable burnups and storage times, fuel assemblies of various sizes, etc.).

From a scientific and technical perspective, ONDRAF/NIRAS taking charge of non-reprocessed irradiated fuel from nuclear power plants should not pose any new problems, including in terms of criticality, because this is already included in the studies. The geological repository is designed to accommodate fuel and is sized according to the waste volumes for disposal. The impact of a potential increase in the burnup of the fuel must however be taken into account in the studies and safety assessments, as well as in the repository design. Indeed, the burnup increase is accompanied by modifications in the radiological composition of the fuel with which a higher thermal impact is associated. This point is the subject of international research. The disposal of irradiated MOX fuel will also require, if necessary, particular attention, essentially due to its thermal load and significant radiotoxicity.

Although according to the current purely technical schedule, category C waste will not be emplaced in a geological disposal facility before 2080 at the earliest (section 9.2), the uncertainty about the status of commercial irradiated fuel will have to be addressed in the relatively short term for various reasons.

- It will have to be addressed to make it possible to establish and develop contacts locally (for example with municipalities) or supra-locally (for example with provincial or regional institutions) in a siting context. Indeed, it is very difficult to conduct participative processes for the long-term management of radioactive waste effectively at local or supra-local level if there are significant uncertainties about the waste concerned (volumes and characteristics). ONDRAF/NIRAS made this observation as part of the category A disposal programme and the same type of observation has been made in other countries.

- It will have to be addressed in order to prepare the licence applications with a view to moving towards the construction of the geological repository. Indeed, it is hardly conceivable for FANC to issue a nuclear licence for the construction and operation of a geological disposal facility without knowing the exact types and volumes of all the waste for disposal, therefore including category C waste, even if this was only to be disposed of several decades after category B waste. The opinion given by FANC within the scope of the legal consultation procedure also specifies: *"FANC recognises that a decision about the status of spent fuel is important within the framework of the decision-making process."* [translation ONDRAF/NIRAS] [109].

- It will have to be addressed to make it possible to remove the assumption about the type of category C waste that ONDRAF/NIRAS will have to take charge of in the future, an assumption that is included in the assessment of the disposal costs and therefore in the calculation of the tariff for taking charge of this waste. The tariff is currently calculated based on the assumption that all irradiated fuel from nuclear power plants will be reprocessed (including MOX fuel). If it turns out that ONDRAF/NIRAS will have to take charge of non-reprocessed irradiated fuel, potentially with very different characteristics, the financing method for taking charge of this waste will have to be changed. The assumption of total reprocessing is cautious from the point of view of the creation of provisions for long-term management by Synatom, because the discounted cost of the reprocessing of irradiated fuel and the geological disposal of reprocessing waste is higher than the cost of direct geological disposal of non-reprocessed irradiated fuel. Solely from the point of view of long-term management, the costs for the direct disposal of irradiated fuel are however greater than those for the disposal of waste arising from reprocessing of the fuel.

Finally, knowing the delivery schedule for future category C waste from Synatom is essential to its proper management by ONDRAF/NIRAS.

- Any change in the schedule has an impact on the overall cost of the disposal project.
- In time, ONDRAF/NIRAS must be able to make the necessary arrangements to take charge of future category C waste, including for example planning for the conditioning, storage and post-conditioning of irradiated fuel with potentially very different characteristics.
- The financing of the long-term fund must be assured so as to allow medium-term and long-term management costs to be covered as they arise. A delay in the delivery of category C waste compared with the planned schedule is likely to have a considerable impact on the evolution of the cash flow of the fund.

The issue of the status of irradiated fuel is therefore a complex one, with potentially very diverse implications on the management of both reprocessing waste and non-reprocessed irradiated fuel declared as waste, including in terms of costs and RD&D requirements, and broadly connected to each other. The difficulty that a lack of clarity regarding the status of irradiated fuel represents for ONDRAF/NIRAS was already highlighted in 2001 in the contextual document of the SAFIR 2 report [18] and in 2007 in the second nuclear liabilities inventory report [42]. It does not allow ONDRAF/NIRAS to optimise its RD&D programme for the disposal of category C waste.

The status of non-reprocessed commercial irradiated fuel must be clarified before the siting process begins.

10.2.2 Belgium's future policy in terms of electricity production

With the Law of 31 January 2003 [68], which bans the construction and operation of new commercial nuclear power plants intended for electricity production and orders the closure of the seven existing nuclear power plants after 40 years of operation, Belgium has committed to gradually phasing out nuclear energy.

However, the possibility of postponing the closure of one or several power plants, as considered in the study by the GEMIX group [66] and the federal study on the prospects for electricity supply [122], leads to a possible increase in the estimated volumes of conditioned waste to be managed. At the request of the GEMIX group, the group of national and international experts charged by the Royal Decree of 28 November 2008 with conducting a study intended to present the Government with one or more scenarios on the ideal energy mix for Belgium, ONDRAF/NIRAS indicatively calculated the impact on these volumes resulting from an extension in the operational period of the seven Belgian nuclear power plants of 10 and 20 years respectively (Table 7). These additional waste volumes were calculated using the rule of proportionality. They only take into account waste from current production, i.e. resulting from the operation of the power plants. Indeed, there is currently no available estimate for the potentially significant waste volumes that could be generated by operations to renew or renovate the infrastructures.

Table 7 – 2009 indicative estimate of the volumes of category A, B and C waste to be managed by 2070, calculated at the request of the GEMIX group and based on the assumption of a 10 and 20 year extension in the operational period of the seven nuclear power plants [66, 69]. There is currently no available estimate for the waste volumes that could be generated by operations to renew or renovate the infrastructures.

		Indicative estimate (7 × 40 years) [m^3]	Indicative estimate (7 × 50 years) [m^3]	Indicative estimate (7 × 60 years) [m^3]
Category A waste				
	Total	69900	73200 + renovation	76500 + renovation
		Source of increase: current production and renovation waste		
Category B&C waste		*if reprocessing resumes (for all fuel)*		
Category B		11100	11500	11900
Category C		600	750	900
	Total	11700	12250 + renovation	12800 + renovation
		Source of increase: – category B: current production waste from power plants and renovation waste – category C: reprocessing waste		
Category B&C waste		*if reprocessing definitively abandoned*		
Category B		10430	10630	10830
Category C		4500	5800	7000
	Total	14930	16430 + renovation	17830 + renovation
		Source of increase: – category B: current production waste from power plants and renovation waste – category C: non-reprocessed irradiated fuel		

B&C waste resulting from an extension in the operational period of nuclear power plants could be disposed of in a geological disposal facility.

- The radiological characteristics of this waste would not pose any new difficulties in scientific and technical terms, since they would, to a large extent, be similar to those of existing waste (for example line b2-7 in annex A1). The impact of a potential increase in the burnup of fuel is however taken into account in the international RD&D programme (section 10.2.1).
- The geological repository in poorly indurated clay (Boom Clay or Ypresian Clays), as recommended by ONDRAF/NIRAS, could be sized in a flexible way according to the waste volumes for disposal. Since the clay formations considered have a large lateral continuity, it is possible to make the repository larger if necessary. Furthermore, the flexibility of a repository in clay in terms of radiological capacity is more than likely sufficient to allow a margin of at least 100% with regard to the radiological inventory of the waste that can be disposed of in the repository.

Financing for the long-term management of B&C waste resulting from an extension in the lifespan of the nuclear power plants could be provided by the existing financing mechanism, by means of tariff corrections in application of the existing contractual mechanisms.

The delivery of dismantling waste from the power plants, which is for the most part category A waste, would however be delayed for the same period as the extension of the operational period of the power plants.

10.2.3 Possible transfer of waste from category A to category B

The current distinction between category A waste and category B waste (which is needed especially for calculating waste tariffs) is based on the provisional working assumptions of ONDRAF/NIRAS regarding the radiological limits applicable to waste for surface disposal.

ONDRAF/NIRAS will propose the radiological limits applicable to waste for surface disposal based on the results of safety calculations and analyses, which take into account the characteristics of the disposal system (design, site, etc.) and the protection criteria imposed by the regulatory framework being developed. These limits will be accepted or amended by the provisions of the licence to construct and operate the repository. The content of a surface disposal facility must indeed be such that its radiological impact after the regulatory control phase does not exceed the safety and protection criteria imposed by the regulations relating to repositories. Other conditions established by the licences related, for example, to the physicochemical characteristics of the waste, could lead to the transfer of some waste from category A to category B. It is therefore likely that some waste currently assumed eligible for surface disposal by ONDRAF/NIRAS will have to be transferred to category B, but a possible transfer of waste in the opposite direction cannot be ruled out.

Any waste transferred from category A to category B could be disposed of in a geological disposal facility without any particular difficulties.

- The radiological characteristics of this waste would not pose any new difficulties in scientific and technical terms, since, logically, it would mainly be long-lived waste, relatively similar to certain category B waste already considered in the studies.
- The geological repository in poorly indurated clay (Boom Clay or Ypresian Clays), as recommended by ONDRAF/NIRAS, could be sized in a flexible way according to the waste volumes for disposal (see also section 10.2.2). To illustrate the idea, the transfer of 5%, or 3500 m^3, of the current estimated volume of category A waste to category B would correspond to a significant increase of over 30% in the estimated volume of category B waste.

Any transfer of waste from category A to category B will lead to tariff corrections in application of the existing contractual mechanisms.

The issue of the possible transfer of waste between categories A and B will be clarified in the coming years within the scope of the category A disposal programme.

10.2.4 Status of enriched fissile materials and plutonium-bearing materials

Within the framework of its mission known as the "inventory of nuclear liabilities", ONDRAF/NIRAS asks nuclear operators about the quantities of radioactive materials that they hold. According to this inventory [42], several nuclear operators hold enriched fissile materials and/or plutonium-bearing materials (materials excluding fuel, as stated in the Royal Decree of 30 March 1981) that they do not declare as excess quantities and therefore do not ask (and have never asked) ONDRAF/NIRAS to take charge of. This situation means that ONDRAF/NIRAS faces the issue of whether or not it will one day have to manage such materials.

The possible taking charge of excess quantities of enriched fissile materials and/or plutonium-bearing materials by ONDRAF/NIRAS should not pose any particular scientific or technical problems. It is particularly the issue of their optimal conditioning (type of matrix) to ensure the non-criticality of the system in long-term management conditions which arises; this is examined internationally. These materials would only give rise to a relatively low volume of conditioned waste, which could be placed in a geological disposal facility.

Taking charge of excess materials with a view to their long-term management would however have to satisfy the requirements of the safeguards that aim to prevent their diversion and use for non-peaceful purposes. The requirements for the long-term management of such materials are currently being developed internationally.

10.2.5 Possible modifications to the inventory of category B radium-bearing waste

The issue of the long-term management of radium-bearing waste present in Belgium is worth special consideration, and will be the subject of a dedicated plan by ONDRAF/NIRAS (section 11.1) with a view to developing a management system for this waste complementary to the current system.

All radium-bearing waste to be managed as radioactive waste in Belgium is comprised, on the one hand, of the radium-bearing waste contained in Umicore's licensed interim storage facilities in Olen and waste resulting from future remediation operations in Olen, and, on the other hand, of the radium-bearing waste stored on the ONDRAF/NIRAS BP1 and BP2 sites operated by Belgoprocess in Mol and Dessel.

Eventually, certain radium-bearing waste currently stored in Umicore's licensed class II UMTRAP facility in Olen, along with the radioactive waste that will result from the remediation of Umicore's D1 landfill site, also in Olen, could, due to requirements of the regulatory framework being developed, have to be transferred to category B. Conversely, it could seem advisable for optimisation reasons to manage the radium-bearing waste currently included in category B (and stored on the BP1 and BP2 sites) with other radium-bearing waste, within the scope of the management system to be developed for radium-bearing waste.

The waste that would be extracted from the UMTRAP facility and the waste that would arise from the remediation of the D1 landfill site and be transferred to category B could be placed in a geological disposal facility.

- The geological repository in poorly indurated clay (Boom Clay or Ypresian Clays), as recommended by ONDRAF/NIRAS, could be sized in a flexible way according to the waste volumes for disposal (see also section 10.2.2). The volume of waste extracted from the UMTRAP facility could range from several thousands of cubic metres to 10000 m^3 (non-conditioned) [164], which would represent a substantial increase in the estimated volume of category B waste, which is approximately 11000 m^3 (conditioned) (see Table 3 in section 4.3.1).

- The radiological characteristics of this waste would not pose any major difficulties in scientific and technical terms. Indeed, it is similar to certain category B waste (particularly radium-bearing waste) already considered in the studies (notably line d-2 in annex A1). The substantial increase in the volume of this waste, and therefore the risk of contamination with radon gas, would however require specific measures at the operational level.

11 Related issues connected to the development of one or more additional management systems

Since ONDRAF/NIRAS is responsible for the long-term management of all radioactive waste present in Belgium, it intends to prepare for various issues regarding substances that currently do not have radioactive waste status, but could subsequently acquire it (see also section 3.2). This preparation will be carried out proportionally to the maturity of the different cases. ONDRAF/NIRAS must also make provisions with a view to preparing for the long-term management of radium-bearing waste with radioactive waste status and which, sooner or later, it will have to take charge of.

The issues identified relate to existing situations, which either concern licensed interim storage facilities, or have been or are likely to be the subject of a radiological remediation decision by FANC. Indeed, by definition, radiological remediation generates radioactive waste (section 3.2.2.4). The different wastes are those given in the two right-hand columns of Table 4 in section 5.1.

- The issue of radium-bearing waste, which covers a highly heterogeneous range of substances and situations (section 11.1), arises unavoidably for ONDRAF/NIRAS: sooner or later, ONDRAF/NIRAS will indeed have to take charge of radium-bearing waste resulting from remediation operations on the Umicore site in Olen or in the surrounding area, along with the radium-bearing waste contained in the UMTRAP and "Bankloop" storage facilities, with a view to providing for their long-term management. The long-term management of radium-bearing waste must be examined within the scope of a global approach to the issue and, consequently, will be the subject of a dedicated plan complementary to the current plan.
- Other types of substances, which currently do not have radioactive waste status and which ONDRAF/NIRAS does not currently have to manage, could eventually have to be taken charge of by ONDRAF/NIRAS: waste from radiological remediation operations to be decided on by FANC within the scope of the NORM and TENORM issue (section 11.2) and/or waste from the remediation of grounds with old diffuse radioactive pollution (section 11.3).

The common point between radium-bearing waste, NORM and TENORM waste and other waste resulting from future remediation operations is that it is all long-lived waste, mostly very low-level and low-level (even medium-level for some radium-bearing waste), distributed over many sites, the volumes of which are potentially considerable. Its long-term management will require ONDRAF/NIRAS to develop one or more management systems complementary to the existing system. Indeed, it is likely that this waste will have to be managed, at least in part, in a decentralised way, on or immediately near to the location where it is found.

The issues related to the development of one or more management systems complementary to the existing management system of ONDRAF/NIRAS do not change either the need for a decision in principle for the long-term management of B&C waste or the solution recommended by ONDRAF/NIRAS for this management.

11.1 Radium-bearing waste

The issue of radium-bearing waste is characterised by the potentially large waste volumes concerned and its radiological characteristics, namely, that this is long-lived waste that is mostly low-level or even medium-level. It is also characterised by the heterogeneity of the materials and substances concerned and the type of place where it is found: it ranges from diffuse radioactive pollution present on various grounds to radium sources and conditioned research and dismantling waste stored in ONDRAF/NIRAS buildings, including more-or-less concentrated contaminations present in landfill sites and contaminated soils and sealed sources stored in licensed storage facilities for which ONDRAF/NIRAS is not responsible.

Radium-bearing waste, which will be the subject of the next long-term management plan of ONDRAF/NIRAS (section 11.1.3), is found mainly on the Umicore site in Olen, and its surrounding area (section 11.1.1). Radium-bearing waste is also stored on the ONDRAF/NIRAS sites operated by Belgoprocess in Mol and Dessel (section 11.1.2).

11.1.1 Umicore site in Olen and the surrounding area

The activities of the radium and uranium extraction plant operated by the former Union Minière (which became Umicore in 2001) between 1922 and 1977 and then dismantled are the source of highly heterogeneous situations in the municipality of Olen: the presence of two licensed, class II, interim storage facilities (section 11.1.1.1), a landfill site that was subject to a remediation decision (section 11.1.1.2), and other landfill sites, as well as grounds containing diffuse radioactive pollution that could be subject to remediation decisions by FANC (section 11.1.1.3) [42].

11.1.1.1 Licensed interim storage facilities (UMTRAP and "Bankloop")

Umicore is responsible for two licensed, class II, interim storage facilities built on its Olen site: the UMTRAP facility and the facility known as "Bankloop". Since, by definition, the waste that they contain is radioactive, sooner or later their long-term management will have to be assigned to ONDRAF/NIRAS. However, Umicore has not yet requested that ONDRAF/NIRAS take charge of this waste.

The UMTRAP facility, built in the 1980s by the former Union Minière, and which was licensed as a class II interim storage facility (Figure 48) in 1991 by the SPRI, the safety authority at that time, contains long-lived and low-level or medium-level non-conditioned waste. This can be broken down as follows [42]:

- radium sources (approximately 200 g of radium-226 in total), residues from uranium extraction (2 000 tonnes, including approximately 700 g of radium-226) and radium-rich residues (500 tonnes, including approximately 60 g of radium-226), which are stored in concrete bunkers covered by a copper confinement barrier;
- radium-poor residues (approximately 8000 tonnes, including approximately 30 g of radium-226), which are stored in silos between the bunkers;
- various residues (approximately 6000 tonnes, including approximately 20 g of radium-226) and contaminated soils (approximately 60000 tonnes, including approximately 20 g of radium-226), which occupy the spaces between the silos and bunkers.

This waste represents a total volume of approximately 55000 m^3 (based on an average density of 1400 $kg \cdot m^{-3}$). The entire facility is covered in clay, sand and gravel.

Figure 48 – Umicore's UMTRAP licensed interim storage facility in Olen. Left: placing of the copper confinement barrier over a concrete bunker; right: overview of the site after the covers have been installed (source: Umicore).

The UMTRAP facility raises various issues regarding its long-term management. Indeed, due to the radiological characteristics of a significant portion of the waste that it contains, it does not satisfy current IAEA [59, 165] and European Commission [166] recommendations for surface disposal. Some of it, which it is up to FANC to specify, could have to be extracted from the facility. So, the issue of its transfer to the future facility for the long-term management of B&C waste, as category B waste (section 10.2.5), or to a dedicated long-term management facility would arise.

The "Bankloop" facility, licensed for 10 years by FANC in 2006, contains approximately 30000 m^3 very low-level and low-level, long-lived non-conditioned waste from the remediation in 2007–2008 of a small stream, the Bankloop, which was previously used to discharge liquid effluents from the plant into the Kleine Nete, about 2000 metres from the Umicore site. These works were performed as the result of a remediation decision made by the SPRI in 2000 [39].

11.1.1.2 D1 landfill site, for which a remediation decision has been made

The D1 landfill site, located outside the Umicore site in Olen, is an area of approximately 10 hectares with approximately 200 000 m^3 of radium-bearing and chemical waste, approximately 10 000 m^3 of which contains dismantling waste from the former Radium laboratories, which are potentially hot spots, i.e. specific zones where the activity is significantly higher than neighbouring activity. It also contains materials from the remediation of contaminated streets of Geel and Olen (see below). (The volume of the landfill may be greater than the radiologically contaminated volume, and this volume may itself be greater than the volume likely to have to be taken charge of by ONDRAF/NIRAS as radioactive waste.)

In 2000, SPRI notified Umicore that the D1 landfill site would have to be subject to radiological remediation [39]. (SPRI would however consider that the D1 landfill site did not present any immediate risk to public health from a radiological perspective, notably due to the inaccessibility of the landfill site, which is fenced off, but that remediation would eventually be necessary.) The waste from this future remediation operation will have radioactive waste status and its long-term management will have to be provided by ONDRAF/NIRAS.

11.1.1.3 Landfill sites and grounds with diffuse radioactive pollution where FANC has not yet decided whether remediation is necessary

The radioactive pollution in Olen appears in a concentrated form in landfill site I and in two locations in landfill site II, and in a diffuse form across the entire Umicore site and across one other zone. FANC has not yet decided whether these landfill sites and grounds should be subject to remediation. The waste from any future remediation operations will have radioactive waste status and its long-term management will have to be provided by ONDRAF/NIRAS.

- *Landfill site I ("Bruine Berg"), on the Umicore site.* Landfill site I has a volume of approximately 200 000 m^3 and contains chemical waste (iron hydroxide, gypsum and lime residues, produced during cobalt manufacture), like landfill site D1. The source of its radioactive contamination is dredging sludge from the Bankloop and possibly also sludge produced during remediation operations of the Umicore site. Radiological characterisation conducted in 2002 confirmed the presence of radium-contaminated materials in the landfill site and was able in particular to locate two more highly contaminated bands. (The volume of the landfill may be greater than the contaminated volume, and this volume may itself be greater than the volume likely to have to be taken charge of by ONDRAF/NIRAS as radioactive waste.)
- *Landfill site II ("MHO/IOK landfill site", also called "D2/D3") outside the Umicore site.* Landfill site II contains industrial waste from the former plant and household waste produced by the workers' estate that previously belonged to Union Minière. Its radioactive contamination is limited to two locations called "D2" and "D3" and is probably due to contaminated demolition materials. Umicore estimates the volume of the contaminated portion to be around 25 000 m^3. (This volume may be greater than the volume likely to have to be taken charge of by ONDRAF/NIRAS as radioactive waste.)
- *Entire Umicore site.* Umicore estimates the quantity of radioactively contaminated materials spread over its site as between 50 000 and 150 000 m^3. Among other

things, these materials are the result of dredging the 1500-metre-long section of the drainage canal that previously connected the plant to the Bankloop. Radiological characterisation conducted in 2003 confirmed the presence of radioactive pollution in several specific places on the site, including in buildings that were used to produce radium and uranium. (The indicated volume may be greater than the contaminated volume, and this volume may itself be greater than the volume likely to have to be taken charge of by ONDRAF/NIRAS as radioactive waste.)

- *Certain streets in Geel and Olen, outside the Umicore site.* There are contaminated materials under the surface of certain streets in Geel and Olen, over a surface area of several hundred square metres.

11.1.2 ONDRAF/NIRAS sites operated by Belgoprocess

Category B radium-bearing waste stored in conditioned or non-conditioned form on the ONDRAF/NIRAS sites operated by Belgoprocess is mainly waste from former SCK•CEN research programmes, waste resulting from the dismantling of the former Union Minière radium and uranium extraction plant in Olen, sources (including lightning conductors, smoke detectors and radium needles), contaminated effluents, and to a lesser extent, waste from the Belgian army (lines c4-19 to c4-24 and d-2 to d-4 in annex A1).

11.1.3 Plan dedicated to the long-term management of radium-bearing waste

ONDRAF/NIRAS will draw up a plan dedicated to the long-term management of radium-bearing waste as soon as possible. This plan will aim to propose a long-term management policy for this waste which will provide the necessary framework for its optimal management given its specific characteristics. It will take into account the regulations in force in terms of radiation protection and radioactive waste management, the directive on the management of waste from extractive industries [167] and Umicore's obligations, especially the obligation, in accordance with the provisions of the Royal Decree N0315 of 20 June 1995, to conduct an assessment of the future management measures necessary with regard to the UMTRAP facility and the obligation to carry out the radiological remediation of the D1 landfill site.

In order to be able to develop fully the future plan dedicated to radium-bearing waste, ONDRAF/NIRAS will however have to be informed by FANC of the general principles to be applied for the long-term management of this waste and to know in a timely manner FANC's position as to whether it is necessary to remediate the various landfill sites and grounds for which a decision is currently pending.

This plan could lead to certain waste from the UMTRAP facility and certain remediation waste from the D1 landfill site being transferred to category B. Conversely, it could also lead to the conclusion that, in terms of optimisation, it would be better to manage existing and planned category B radium-bearing waste within the framework of a management system specific to all radium-bearing waste rather than to manage this waste with the other B waste and the C waste.

11.2 Radioactive waste from remediation operations related to work activities that could be decided by FANC

Certain industrial activities involving raw materials containing naturally radioactive substances, without the radioactive character being a sought-after property of these substances, are likely to generate situations that cannot be ignored for radiation protection reasons. These activities, called *work activities* in the general regulations on the protection against ionising radiation [35, 43], can for example involve production processes which concentrate the natural radioactivity in the residues resulting from the processes. So far, these have not been subject to nuclear licences, but since 1 September 2003 have had to be declared to FANC.

Raw materials and the residues resulting from standard industrial processes that contain non-negligible quantities of natural radionuclides and may therefore lead to a risk of exposure to ionising radiation are designated by the acronyms NORM (naturally occurring radioactive materials) and TENORM (technologically enhanced, naturally occurring radioactive materials), respectively.

Anticipating the implications of the general regulations on the protection against ionising radiation, which includes in its article 4 a list of work activities likely to lead to long-term exposure situations, in the framework of its nuclear liabilities inventory mission, ONDRAF/NIRAS subcontracted SCK•CEN to conduct the first study in Belgium aimed at drawing up an overview and producing a first assessment of work activities that could require radiological protective measures. According to this study, published in 2003 [168], the main sectors of the non-nuclear industry that use or have used natural radiation sources are as follows:

- the phosphate industry,
- the use of zircon sands,
- the cement industry,
- the non-ferrous industry,
- the steel industry,
- coal power plants,
- thorium applications,
- groundwater capture,
- the coal industry,
- alum extraction.

The three sectors where the NORM and TENORM issue can be seen most clearly are the phosphate industry (phosphate fertilisers), the use of zircon sands and the cement industry. In the phosphate industry for example, the total volume of residues (gypsum and sludge) potentially unable to be ignored in terms of radiation protection, and therefore requiring protective measures, has been estimated at 35 million cubic metres.

The NORM and TENORM issue was introduced as part of the radiation protection regulations by European Directive 96/29 [43]. Since the late 1990s it has been the subject of growing attention both in Belgium and internationally. If FANC judges that certain situations must be subject to radiological remediation, ONDRAF/NIRAS will examine the issue of these remediation operations in consultation with FANC, if necessary within the framework of a new management plan, taking into account the number of sites to be remediated, the volumes of NORM and TENORM radioactive waste (very low-level, even low-level and long-lived) that could result from these remediation operations and that would have to be managed in the long term, along with the possibilities for the long-term management of this waste.

Also, the “waste” status of residues from processes used in work activities is not always clear. Residues from some of these activities are indeed used as raw materials for other work activities. In addition, new recycling channels are currently being considered. This may help to reduce the volumes of residues ultimately to be considered as radioactive waste.

11.3 Radioactive waste from remediation operations of grounds with old diffuse radioactive pollution that could be decided by FANC

Separately from the Umicore site in Olen and its surrounding area, some grounds have old diffuse radioactive pollution resulting from past, nuclear or work activities. Thus, the Molse Nete has historical pollution caused by various nuclear operators in the Mol–Dessel region and the Grote Laak and the Winterbeek, in the Tessenderlo region, were polluted in the past by discharges from the phosphate industry.

Long-term management methods for radioactive waste from remediation operations of grounds with old diffuse radioactive pollution that would be decided on by FANC will in principle be evaluated on a case-by-case basis, in particular depending on the scale of the remediation operations from which the radioactive waste to be managed will result, the quantity and characteristics of this waste, and the characteristics of the grounds to be remediated.

11.4 Addition to the existing legal and regulatory framework

In consultation with ONDRAF/NIRAS and the Regions, which are involved as competent authorities in terms of environmental protection, FANC is currently developing the regulatory instruments necessary to assess situations likely to require intervention and make any necessary intervention decisions. Largely subsequent to the creation of ONDRAF/NIRAS and the definition of its management system, this regulation will add a new component to radioactive waste management.

Decisions about interventions will be made following a stepwise procedure which is inspired, in its progressive aspects, by regional regulation relating to soil remediation in the case of non-radioactive pollution (soil guidance study, soil description study, soil remediation project).

The procedure being developed defines

- the roles of the various parties involved, particularly ONDRAF/NIRAS for the long-term management aspects of radioactive waste from remediation operations;
- the decisions to be made;
- the various cases on which to base these decisions and their content;
- the criteria to be used to assess the radiological risks and balance them against the chemical risks.

The regulatory framework being developed provides that in the event of an intervention decision giving rise to the production of radioactive waste, in other words, in the event of a remediation decision, the long-term management of this radioactive waste must be an integral part of the chosen remediation scenario.

The promulgation of these regulatory instruments in the form of law and/or royal decree is currently being prepared by FANC.

4

Part 4

Conclusions and recommendations

12 Conclusions and recommendations

In order to fulfil its radioactive waste management mission successfully, ONDRAF/NIRAS must be able to provide a final destination for all the waste that it takes charge of.

Contrary to the situation for category A waste, Belgium does not have a formally approved institutional policy for the long-term management of existing and planned (mainly within the scope of the current nuclear power programme) B&C waste, including non-reprocessed irradiated nuclear fuel declared (or likely to be declared) as waste, as well as excess quantities of enriched fissile materials and plutonium-bearing materials declared (or likely to be declared) as waste. However, such a policy is *essential* for establishing the final destination of this waste and, therefore, for focusing the RD&D still needed, for determining and optimising all aspects of its management, and for applying the "polluter pays" principle on a firmer basis. Moreover, it is the responsibility of the countries that are signatories to the Joint Convention of 1997 on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, which includes Belgium, to have a long-term management policy for this waste. This national responsibility is one of the founding principles of the European "Waste" Directive of 19 July 2011 (annex A2).

According to ONDRAF/NIRAS, the Waste Plan contains all the necessary elements to enable the Government to make a fully informed *decision in principle* for the long-term management of existing and planned B&C waste.

The launch of the implementation of the Waste Plan, adopted by the ONDRAF/NIRAS Board of Directors on 23 September 2011, must be approved by a decision in principle from the Federal Government, establishing a clear policy for the long-term management of B&C waste. This implementation will include a series of actions enabling the implementation of the chosen long-term management solution, such as the choice of a host formation, the choice of potential construction zones, the formalisation of processes and structures for societal dialogue, the choice of one or several sites, the local integration of the solution, and the licence applications. The gradual development of this management policy will require the establishment of an appropriate normative system, which is currently lacking.

In practical terms, for the long-term management of existing and planned B&C waste, ONDRAF/NIRAS recommends a global geological disposal solution that combines technical, decision-making and societal aspects (section 12.1). ONDRAF/NIRAS also formulates a series of proposals and recommendations relating to issues, the answers to which are not a matter solely for ONDRAF/NIRAS, but which impact or are likely to impact its management activities (section 12.2). Both the recommended global solution and the proposals and recommendations help to comply with the requirements of the European "Waste" Directive of 19 July 2011 (annex A2).

12.1 The solution recommended by ONDRAF/NIRAS for the long-term management of B&C waste

The solution recommended by ONDRAF/NIRAS for the long-term management of B&C waste is a global solution, in that it provides a technical solution (section 12.1.1) that fits into a decision-making process integrating the technical and societal aspects (section 12.1.2), the development and implementation of which are accompanied by a series of conditions arising from the societal consultation organised on the initiative of ONDRAF/NIRAS and from the legal consultation (section 12.1.3).

12.1.1 Technical solution for the long-term management of B&C waste

The technical solution recommended by ONDRAF/NIRAS for the long-term management of B&C waste is a solution that can become definitive, namely

- geological disposal (section 12.1.1.1)
- in poorly indurated clay (Boom Clay or Ypresian Clays) (section 12.1.1.2)
- in a single facility (i.e. one facility for all B&C waste and built at a single site) (section 12.1.1.3)
- on Belgian territory (section 12.1.1.4)
- as soon as possible, but with the pace of development and implementation of the solution needing to be proportionate to its scientific and technical maturity, as well as its societal support (section 12.1.1.5).

This technical solution is *sufficiently mature to be subject to a decision in principle*, since the uncertainties still to be addressed are not considered prohibitive.

The other envisaged management solutions that can become definitive either contravene the national or international regulatory framework, or do not offer the desired degree of long-term safety (this is particularly the case with eternal storage, where safety depends on the continuity of the maintenance actions and the societal context), or are not compatible with the total volume of B&C waste to be managed (as is the case for deep borehole disposal). Furthermore, a choice in favour of surface storage other than interim storage as is currently practised cannot, according to the safety authority (FANC), be justified.

12.1.1.1 Geological disposal

Geological disposal

- is in line with the legal mission of ONDRAF/NIRAS, as it provides a final destination for B&C waste;
- is applicable to all existing and planned B&C waste;
- is considered by radioactive waste management organisations and safety authorities at national and international level as feasible and capable of ensuring the protection of man and the environment for several hundreds of millennia, in a robust way and in an intrinsically passive manner (i.e. without human intervention being required, which does not however mean the absence or impossibility of controls): passive safety is guaranteed primarily by appropriate design of the disposal system (sound choice of host formation, suitable design of engineered barriers for the repository and adequate conditioning and post-conditioning of the waste) and through implementation that conforms to the design;
- is confirmed by the results of the multidisciplinary analysis of possible management options carried out within the scope of the SEA as being *the only solution for the long-term management of B&C waste and certainly the safest from a radiological point of view, the most robust in terms of future societal and natural evolution, and the most appropriate to protect man and the environment in the long term*;
- minimises the burdens transferred to future generations, in particular radiological risks, environmental impact and responsibility for ensuring safety, making decisions and ensuring financing;
- can be financed on the basis of the "polluter pays" principle;
- has been chosen by all countries that have an institutional policy for the long-term management of their B and/or C waste. The United States has operated since 1999 a geological disposal facility for its category B military waste, and Finland, France and Sweden are, in principle, only 10 to 15 years away from starting the industrial operation of a geological disposal facility.

12.1.1.2 In poorly indurated clay (Boom Clay or Ypresian Clays)

Poorly indurated clays, in particular Boom Clay and Ypresian Clays, are the geological formations in Belgium that seem to present the best intrinsic properties to ensure the functions expected of a natural barrier, i.e. long-term isolation, confinement and retention of radionuclides and chemical contaminants present in a geological disposal facility. An appropriately designed and implemented disposal system in these clays can ensure safety in the long term.

Scientific and technical knowledge in the field of disposal in poorly indurated clay, in particular 30 years of RD&D in the HADES underground laboratory, has been assessed several times by Belgian and foreign experts. Their conclusions can be summarised as follows.

- The findings are based on sound science and have reached a sufficient degree of maturity for a favourable opinion to be given on the safety and feasibility of this solution. Current research in other countries confirms the potential of clay formations for confining disposed waste and retaining radionuclides and chemical contaminants.

- The remaining uncertainties are systematically analysed and taken into account in the safety and feasibility assessments, which show that these uncertainties do not call into question the safety and/or feasibility of this solution. Reducing uncertainties is central to current and future RD&D programmes.

Continuing RD&D will enable the gradual confirmation and refinement of knowledge, so as to increase safety margins and reduce remaining uncertainties, as well as optimise the disposal system. The protection of aquifers surrounding the host formations will be one of the focal points of this continuing RD&D.

It is of course up to FANC and the authorities competent to deal with environmental protection to assess, within the scope of the licence application procedure for geological disposal, the degree of safety and protection provided by the disposal system developed, and to authorise its implementation.

The validity of activities with regard to disposal in poorly indurated clay has also been confirmed several times by different Belgian commissions and working groups asked by institutional bodies to give an opinion on various issues including, to varying degrees, radioactive waste management.

A choice in favour of geological disposal in poorly indurated clay for the long-term management of B&C waste limits the areas of the Belgian territory where a repository could be located to the north-east and the northernmost part of western Belgium. However, this choice does not imply that a site has to be chosen immediately.

12.1.1.3 In a single facility

According to ONDRAF/NIRAS, category B and category C wastes must be managed in the long term within the scope of a management solution — geological disposal — which, on the one hand, is common to both types of waste, since the risk they pose in the long term stretches over similar timescales, i.e. several tens or hundreds of millennia, and, on the other hand, is implemented at a single site, since their respective volumes are such that different facilities cannot reasonably be envisaged from an economic point of view. The geological disposal facility will, however, be designed and operated in such a way that waste with different properties will be placed sequentially and in different parts of the repository.

12.1.1.4 On Belgian territory

ONDRAF/NIRAS considers that B&C waste (as well as the other waste for which it is responsible) must be managed within a national framework and, therefore, on Belgian territory. Since Belgium decided in the 1960s to use nuclear power to produce a large part of its electricity, and since most of Belgium's radioactive waste originates from the nuclear fuel cycle, it is Belgium's responsibility to ensure the management of its radioactive waste, regardless of its future energy policy. This position is in line with the recommendations and regulations in force at international level, which emphasise the responsibility of each country for the management of its own radioactive waste.

12.1.1.5 As soon as possible

Geological disposal ought to start as soon as possible, in light of the scientific, technical, societal and regulatory constraints to be taken into account. In other words, the pace of development and implementation of the disposal solution will have to be proportionate to its scientific and technical maturity, as well as its societal support: programme dynamics will have to be maintained, but without taking any shortcuts.

Implementing geological disposal as soon as possible aims to

- enable ONDRAF/NIRAS to have a complete (closed) management system for B&C waste, which can be optimally organised, and thus to fulfil its mission;
- enable ONDRAF/NIRAS to assess the effective cost of disposal, and hence to apply the "polluter pays" principle on a firm basis;
- ensure the maintenance of expertise and know-how at national level, in particular in the fields of waste knowledge, RD&D and assessment of disposal system performances, which makes an essential contribution to safety;
- avoid increasing the burden of the responsibility for management, including all associated burdens, passed on to future generations and avoid extending the uncertainty for the municipalities on whose territory the waste is currently stored for a temporary, yet indefinite, period.

Since the development and implementation of a global geological disposal solution integrates scientific, technical, decision-making and societal aspects, the timing of the development and implementation programme cannot be established *a priori*, but will instead be determined gradually by a number of factors (RD&D evolution and results, building and maintenance of societal support, siting process, content of the decisions made in the course of the decision-making process, etc.).

From a strictly technical point of view, in light of current knowledge, geological disposal of the first waste, which will be category B waste, cannot be envisaged before 2035–2040. It will take at least fifteen years to implement participative processes, to refine, confirm and optimise the recommended solution by means of RD&D activities, to strengthen societal support, especially through the siting process, and to prepare and submit the licence applications and then obtain the necessary licences, in particular the nuclear licence for construction and operation. It would take about fifteen years to build the repository.

12.1.2 Decision-making process

The development and implementation of the recommended technical solution fit into a decision-making process that integrates the technical and societal aspects. ONDRAF/NIRAS wishes this process to progress in steps, to be adaptable, participative and transparent, and to ensure continuity. It will run for a period of approximately one hundred years from the moment a decision in principle is made, since decisions will have to be made at least until the closure of the repository.

The outline of decision-making process drafted by ONDRAF/NIRAS will serve as a basis for discussion, to be improved, refined, or modified through dialogue with all stakeholders. At this stage, the institutions concerned in bordering countries will be informed on an *ad hoc* basis. This dialogue, which ONDRAF/NIRAS intends to launch without delay, will start by identifying the stakeholders that will be taking part in the decision-making process. It must allow a decision on who will decide what, when, on what basis and using what methods. With the exception of the provisions of the Law of 13 February 2006, there is currently in fact no normative system that describes how to complete the different steps between a decision in principle on the long-term management of radioactive waste and the nuclear licence application needed to implement the management solution chosen. Identification of such things as the key decisions to be made, the stakeholders taking part in the different steps of the decision-making process and their respective roles and responsibilities, and the documentation to be prepared, presents a major challenge. This dialogue, the financing of which also has to be organised, will help to begin to establish a participative process in the B&C programme.

The decision-making process should be included in the normative system to be established, which will have to provide ONDRAF/NIRAS and all stakeholders with whom it will cooperate with a sufficiently stable and well-defined framework for the development and implementation of the recommended technical solution.

The normative system to be established should include the creation of an independent monitoring body entrusted with the responsibility of ensuring that the decision-making process advances in completely documented steps, that it is adaptable, participative and transparent, and that it ensures continuity and integration of the societal and technical aspects.

12.1.3 Conditions arising from the consultations

ONDRAF/NIRAS considers that the development and implementation of the technical solution it recommends will have to meet conditions arising from the consultations, in addition to the applicable standards and regulations. These conditions result from concerns that are largely shared by the public and from concerns expressed by the official institutions consulted. Some of the conditions pertain to the development and implementation of a solution for the long-term management of radioactive waste and have been transposed by ONDRAF/NIRAS to the specific case of geological disposal (section 12.1.3.1), while other conditions have to do with the need to follow up developments regarding management possibilities that were examined in the Waste Plan but were discarded (section 12.1.3.2).

Other societal concerns, in particular the need for independent monitoring of the decision-making process, have been included in the technical solution and/or the decision-making process outlined by ONDRAF/NIRAS.

12.1.3.1 Conditions linked to the development and implementation of the recommended technical solution

In general, the public, whether or not it is in favour of a geological disposal solution, considers that it must be possible to retrieve the radioactive waste from the facility in which it has been placed, that it must be possible to control that the facility is functioning properly and is safe, and that knowledge of both the waste and the facility must be transferred from one generation to the next.

ONDRAF/NIRAS intends to take account of these requests in developing and implementing the geological disposal solution it recommends. *The scope of these requests will have to be further specified in dialogue with all stakeholders, taking into account the need to meet the requirements regarding safety and technical and financial feasibility.*

In this context, ONDRAF/NIRAS undertakes to

- ensure the reversibility of disposal during operation and examine the measures that could facilitate the possible retrieval of the waste after partial or complete closure of the disposal facility for a period that is yet to be defined. However, enhancing retrievability in the design and implementation of a disposal facility cannot occur at the expense of safety, security or safeguards; enhancing retrievability could have an impact on the cost of the disposal facility;
- maintain the controls of the proper functioning of the repository, which will be performed in addition to regulatory controls, for a period that still has to be agreed with stakeholders. However, these controls cannot be performed at the expense of perturbing the system and thus its proper functioning;
- prepare in the most appropriate way the transfer of knowledge about the repository (including institutional memory of its location) and the waste it contains to future generations. This transfer can be organised at both national and international level, in particular by means of the reports to be provided under international obligations. However, it will be up to each generation to determine what knowledge and resources it wants to transfer to the next generation.

12.1.3.2 Follow-up conditions

In parallel with the development and implementation of the geological disposal solution it recommends, ONDRAF/NIRAS will continue to follow up developments regarding management possibilities that were examined in the Waste Plan but were discarded. So it will continue to

- follow the evolution of knowledge on schistose formations on their own and as possible host formations, in order to maintain a fallback solution on Belgian territory if poorly indurated clays are eventually rejected;
- follow the evolution of knowledge on disposal in deep boreholes, in order to have, if needed, a solution for the long-term management of very limited amounts of waste, the retrieval of which one would like to make particularly difficult;
- follow, through international institutions, the evolution in the development of geological repositories shared by several European Union Member States in order

to understand policies on this matter and their potential impact on the Belgian programme;

- maintain a technology watch on national and international developments in the field of advanced nuclear technologies, although these technologies will not make any contribution to the long-term management of existing and planned conditioned waste. This technology watch is justified by the fact that, on the one hand, the policy for the management of commercial irradiated fuel from the current nuclear estate has not yet been determined, and, on the other hand, the research facilities dedicated to advanced nuclear technologies will themselves generate waste that will have to be managed in the long term.

12.2 Proposals and recommendations on related issues the answers to which are not a matter solely for ONDRAF/NIRAS

The proposals and recommendations on related issues, the answers to which are not a matter solely for ONDRAF/NIRAS, but which impact or will impact its management activities, can be divided into two groups: issues relating to the long-term management of B&C waste, and issues concerning the development of one or more additional management systems.

12.2.1 Long-term management of B&C waste

In order to be able to fulfil its mission related to B&C waste management, ONDRAF/NIRAS must not only have confirmation of the solution it recommends for the long-term management of this waste, but it must also

- have a regulatory framework in place that is sufficiently clear and exhaustive for the geological disposal of B&C waste;
- be able to anticipate in a timely manner any variations in the volumes and types of B&C waste to be disposed of.

These issues are not a matter solely for ONDRAF/NIRAS.

More specifically,

- *as far as the specific regulatory framework for geological disposal of B&C waste is concerned,*
  - ONDRAF/NIRAS would like this framework, which is currently being developed by FANC, to be available as soon as possible;
- *as far as the capacity of anticipating in a timely manner any variations in the volumes and types of B&C waste to be disposed of is concerned,*
  - ONDRAF/NIRAS recommends that the status (resource or waste) of irradiated nuclear fuel from commercial reactors be clarified;
  - ONDRAF/NIRAS recommends that the status (resource or waste) of the enriched fissile materials and plutonium-bearing materials (materials excluding fuel, as stated in the Royal Decree of 30 March 1981) be clarified;

- ONDRAF/NIRAS recommends that its opinion be sought in a timely manner by the competent authorities on all issues in which decisions likely to have a significant impact on radioactive waste management (for instance resorting to the reprocessing of irradiated fuel, increasing fuel burnup, designing a major new nuclear facility, remediating a site with radioactive pollution) must be made.

However, the fact that a specific regulatory framework for geological disposal of B&C waste is not yet available and the uncertainties about possible variations in the volumes and types of B&C waste to be disposed of do not call into question the need for a decision in principle and the possibility of making this decision.

12.2.2 Development of one or more additional management systems, in particular for radium-bearing waste

Since ONDRAF/NIRAS must ensure the long-term management of all radioactive waste on Belgian territory, it intends to be prepared to address different issues concerning substances that currently do not have radioactive waste status, but could acquire it later on. These issues concern existing situations for which radiological remediation decisions were made or are likely to be made by FANC. ONDRAF/NIRAS also intends to prepare itself to cope with the issue of long-term management of radioactive waste contained in licensed interim storage facilities for which no application has yet been submitted to ONDRAF/NIRAS to take charge of it. These various issues essentially concern radium-bearing waste and NORM and TENORM waste. The preparation will be carried out proportionally to the maturity of the different cases.

The long-term management of radioactive waste resulting from future remediation operations and of radioactive waste contained in the licensed interim storage facilities will prompt ONDRAF/NIRAS to develop one or more management systems complementary to the existing system. In fact, these wastes are all long-lived, mainly of very low and low radioactivity levels, spread across numerous sites, and represent potentially considerable volumes.

In concrete terms, ONDRAF/NIRAS will in the coming years draw up a dedicated plan for the long-term management of radium-bearing waste present on the Umicore site in Olen and in the surrounding area, as well as of radium-bearing waste already in its storage facilities. This plan will aim to propose a long-term management policy for these wastes, which will provide the necessary framework for their optimal management, taking account of their specific characteristics. In order to develop a comprehensive plan, ONDRAF/NIRAS will, however, have to be informed by FANC about the general principles applicable to the long-term management of radium-bearing waste and to know in a timely manner FANC's position as to whether or not it is necessary to remediate the different landfill sites and grounds in Olen for which a decision is currently pending.

Moreover, if FANC decides that some other situations (situations pertaining to the NORM and TENORM issue or regarding the existence of old diffuse radioactive pollution on certain grounds) must be subject to radiological remediation, ONDRAF/NIRAS will examine the issue of these remediation operations in consultation with FANC, within the scope of a new management plan as the case may be. This examination will notably take into account the number and characteristics of the sites to be remediated, the volumes and characteristics of radioactive waste (NORM and TENORM or others) which could result from remediation operations and which would have to be managed in the long term, as well as the possibilities for the long-term management of this waste.

The prospect of a plan dedicated to the long-term management of radium-bearing waste and, if necessary, of one or more subsequent plans, does not call into question the considerations and findings concerning category B waste and category C waste developed in the Waste Plan: this existing and planned waste can be managed in the long term within the scope of the global solution recommended by ONDRAF/NIRAS.

Annexes

A1 Origins and characteristics of B&C waste

B&C waste comes from a diverse range of origins and has various characteristics. The table overleaf gives an estimate, at the end of 2010, of existing and planned (mainly within the scope of the 40-year operation of the seven current nuclear power plants and their dismantling [36]) B&C waste. It does not cover the modifications that would result from the transfer of waste between categories A and B (section 10.2.3), those that would result from the declaration of enriched fissile materials and plutonium-bearing materials as waste (section 10.2.4), and those relating to potential modifications in the inventory of category B radium-bearing waste (section 10.2.5). However, none of these potential modifications calls into question the need for a decision in principle for the long-term management of B&C waste and the possibility of making such a decision.

The ONDRAF/NIRAS official technical inventory is currently being updated. It should be available in early 2012.

Origin and characteristics of wastes of categories B and C

Production and previsions at end 2010

Origin		Category	Class	Description	Matrix	Primary package (PP) Number	Type
a - Fuel fabrication							
	a-1	B	LAGAL	Low-level alpha-bearing solid waste	cement	**1090**	steel, 400 litres
b - Electricity production							
b1 - Nuclear power plants							
Operation	b1-1	B	MAGAL	Tihange, thermocompacted resins	cement	**440**	steel, 400 litres
	b1-2	B	M / L AGAL	Doel/Tihange, various medium- and low-level solid waste	cement	**40**	steel, 400 litres
	b1-3	B	LAGAL	Doel/Tihange, various low-level solid waste	cement	**47**	reinforced concrete, 1000 litres
	b1-4	B	LAGAL	Doel/Tihange, various low-level solid waste	cement	**24**	reinforced concrete, 1600 litres
Dismantling	b1-5	B	MAGAL	Doel/Tihange, solid components of reactor cores	--	**850**	cast iron, MOSAIK, 1300 litres
b2 - Irradiated fuel from nuclear power plants							
Reprocessing (1)	b2-1	C	ZAGALC	Doel1/2 and Tihange 1, main dissolution stream of fuel reprocessing at The Hague	glass	**387**	steel, CSD-V, 180 litres
	b2-2	B	HAGALC2	Doel1/2 and Tihange 1, compacted structural waste of fuel reprocessing at The Hague	--	**432**	steel, CSD-C, 180 litres
	b2-3	B	HAGALC3	Doel1/2 and Tihange 1, secondary streams of fuel reprocessing at The Hague	glass	**62**	steel, CSD-B, 180 litres
Possible further reprocessing of irradiated fuel assemblies (1)	b2-4	C	ZAGALC	All power reactors, main dissolution stream of fuel reprocessing at The Hague	glass	**2828** (2)	steel, CSD-V, 180 litres
	b2-5	B	HAGALC2	All power reactors, compacted structural waste of fuel reprocessing at The Hague	--	**3760** (2)	steel, CSD-C, 180 litres
or							
Irradiated fuel assemblies	b2-6	C	ZAGALS	MOX irradiated fuel assemblies (all unloaded today)	(3)	**144**	steel box, 275 litres
	b2-7	C	ZAGALS	UOX irradiated fuel assemblies	(3)	**10250**	steel box, 200 to 325 litres
c - Research, development and nuclear pilots - Waste management							
c1 - Irradiated fuel from research reactors: not reprocessed							
	c1-1	C (3)	ZAGALS (3)	BR3 and VENUS irradiated fuel (UOX and MOX)	(3)	**85** (3)	(3)
	c1-2	B	MAGAL	THETIS (UOX) irradiated fuel and fresh UOX powder	cement	**7**	steel, 400 litres
	c1-3	B	LAGAL	BR1 irradiated fuel, uranium metal	(3)	**70** (3)	(3)
c2 - Irradiated fuel from research reactors: reprocessing abroad							
	c2-1	C	ZAGALC	Main dissolution stream of BR2 fuel reprocessing at The Hague	glass	**5**	steel, CSD-V, 180 litres
	c2-2	B	HAGALC2	Compacted structural waste of BR2 fuel reprocessing at The Hague	--	**6**	steel, CSD-C, 180 litres
	c2-3	B	MAGALD	Main dissolution stream of BR2 fuel reprocessing at Dounreay	cement	**123**	steel, 500 litres
c3 - Irradiated fuel reprocessed at the Eurochemic plant							
	c3-1	B	HAGALP1	Main dissolution effluents from Eurochemic reprocessing of high enriched fuel, conditioning in Pamela	glass	**934**	steel, 60 litres
	c3-2	B	HAGALP1	Main dissolution effluents from Eurochemic reprocessing of low enriched fuel, conditioning in Pamela	glass	**467**	steel, 60 litres
	c3-3	B	HAGALP1	Main dissolution effluents from Eurochemic reprocessing of low enriched fuel, conditioning Pamela VITROMET	glass / lead	**100**	steel, 60 litres
	c3-4	B	HAGALP2	Main dissolution effluents from Eurochemic reprocessing of high enriched fuel, conditioning in Pamela	glass	**702**	steel, 150 litres
	c3-5	B	HAGALP3	Eurochemic undissolved residues (fuel, claddings, structures)	cement	**115**	steel, 150 litres
	c3-6	B	MAGALE	Eurochemic medium-level effluents, conditioning in Eurobitum	bitumen	**11487**	steel, 220 litres

c - Research, development and nuclear pilots - Waste management (continued)						
c3 - Irradiated fuel reprocessed at the Eurochemic plant						
c3-7	B	MAGALE	Eurochemic medium-level solid waste, conditioning in Eurobitum	bitumen	**82**	steel, 220 litres
c3-8	B	MAGALE	Eurochemic medium-level solid waste, high reactivity metal, conditioning in Eurobitum	bitumen	**17**	steel, 200 litres
c3-9	B	MAGALE	Eurochemic medium-level effluents, conditioning in Eurobitum	bitumen	**9**	steel, 330 litres
c4 - Operation and dismantling						
c4-1	B	HAGALBE	Beryllium metal and stainless steel components, BR2 reactor	sand / cement	**17**	steel, 150 litres
c4-2	B	MAGALBE	Beryllium metal components, BR2 reactor	sand / cement	**41**	steel, 400 litres
c4-3	B	MAGALE	Medium-level effluents, various origins (4), conditioning in Eurobitum	bitumen	**1950**	steel, 220 litres
c4-4	B	MAGAL	Medium-level solid waste, various origins (4), conditioning in Pamela or HRA Solarium	cement	**400**	steel, 400 litres
c4-5	B	M / L AGAL	Medium- and low-level effluents, various origins (4), conditioning in Mummie	bitumen	**140**	steel, 400 and 220 litres
c4-6	B	MAGAL	Operational and dismantling waste of the Pamela vitrification unit, medium level	cement	**277**	steel, 200 litres
c4-7	B	MAGAL	Medium-level solid waste from BR3 dismantling and BR2 operation	cement	**67**	steel, 400 litres
c4-8	B	MAGAL	Medium-level effluents	(3)	**1350** (3)	steel, 400 litres
c4-9	B	MAGAL	Medium-level solid waste	(3)	**100** (3)	steel, 400 litres
c4-10	B	LAGAL	Eurochemic low-level solid waste, conditioning in 123	cement	**52**	steel / cement, 2200 litres
c4-11	B	LAGAL	Eurochemic and SCK•CEN low-level solid waste, conditioning in 123	cement	**167**	steel, 400 litres
c4-12	B	LAGAL	Low-level solid waste, various origins (4), conditioning in Pamela or HRA Solarium or CILVA	cement	**1230**	steel, 400 litres
c4-13	B	LAGAL	Low-level solid waste, various origins (4), conditioning in HRA Solarium	cement	**21**	steel / cement, 2500 / 3300 litres
c4-14	B	LAGAL	Low-level solid waste, various origins (4), conditioning in alpha-room	bitumen	**1650**	steel, 220 litres, overpacked
c4-15	B	LAGAL	Low-level solid waste, various origins (4), conditioning in alpha-room, further reconditioned	bitumen / (cement)	**109**	steel, 220 litres, overpacked
c4-16	B	LAGAL	Low-level solid waste and compacted ashes, various origins (4)	bitumen	**571**	steel, 220 litres, overpacked
c4-17	B	LAGAL	Low-level waste	(3)	**600** (3)	steel, 400 litres
c4-18	B	LAGAL	Low-level waste, characterization underway	(3)	**32**	steel, 600 litres
c4-19	B	RAGAL (5)	Dismantling waste of the SCK•CEN "Actinium" programme	cement	**72**	steel, 400 litres, overpacked
c4-20	B	RAGAL (5)	Solid radium-bearing waste, conditioning in HRA Solarium	cement	**160**	steel, 430 litres
c4-21	B	RAGAL (5)	Radium-bearing effluents, conditioning in HRA Solarium	cement	**120**	steel, 430, 1400 and 3300 litres
c4-22	B	RAGAL (5)	Radium-bearing waste, conditioning in CILVA	cement	**3200**	steel, 400 litres
c4-23	B	RAGAL (5)	Radium-bearing effluents, conditioning in Mummie	bitumen	**636**	steel, 400 litres
c4-24	B	RAGAL (5)	Radium-bearing waste	(3)	**200** (3)	steel, 400 litres
d - Others						
d-1	B	MAGAL	Medium-level effluents (mainly from IRE)	(3)	**150** (3)	steel, 400 litres
d-2	B	M / L / R AGAL (5)	Radioactive sources, lightning conductors, radium needles, smoke detectors,…, conditioning in CILVA	cement	**800**	steel, 400 litres
d-3	B	RAGAL (5)	Dismantling waste of the radium production unit, Olen site	cement	**222**	steel, 400 litres, overpacked
d-4	B	RAGAL (5)	Radium-bearing waste from the Belgian army	sand / cement	**35**	steel, 400 litres

The production of primary packages is completed.

The type of waste depends on whether reprocessing resumes or is abandoned.

(1) The extracted uranium and plutonium are valued.
(2) This information will be adapted based on production feedback, as follows: 3732 PP type CSD-V and 3153 PP type CSD-C.
(3) Treatment / conditioning still to be confirmed.
(4) Contains mainly wastes from origin "c"; contains some wastes from other origins.
(5) Radium-bearing waste will be the subject of a dedicated plan, which might impact the current category B waste inventory. The radium-bearing waste present at the Umicore site is presently not part of this inventory.

A2 The Waste Plan's contribution to compliance with the requirements of the "Waste" Directive

Noting that the management of irradiated fuel and radioactive waste ultimately remains the responsibility of Member States and that many countries still have not made the necessary key decisions regarding this management, which risks having negative consequences environmentally, economically and socially and imposing undue burdens on future generations, the European Commission considered that it would be advisable to establish a legal framework for the management of irradiated fuel and radioactive waste. On 19 July 2011, the Council of the European Union adopted a Euratom directive, called the "Waste" Directive, establishing a community framework for the responsible and safe management of spent fuel and radioactive waste [169]. This Directive includes a number of points that are directly related to the Waste Plan (see inset).

Several key points of the 2011 European Directive on the safe and responsible management of spent fuel and radioactive waste directly related to the Waste Plan

Introductory comment: the terminology of the Directive has been changed slightly to give greater consistency with the terminology used in the Waste Plan.

The Directive ensures that Member States make the appropriate national arrangements for a high level of safety in irradiated fuel and radioactive waste management and provide the necessary public information and participation. Its scope covers all steps for irradiated fuel and radioactive waste management from civilian activities, from generation until final disposal.

Specifically, the Directive requires the Member States concerned to establish and maintain national policies for irradiated fuel and radioactive waste management. These policies will have to comply with a series of principles, including:

- long-term management relying on passive safety measures;
- the "polluter pays" principle;
- an evidence-based and documented decision-making process governing all management steps;
- the disposal of radioactive waste and irradiated fuel considered as waste on the territory of the Member State in which it was generated.

The Directive also requires the Member States concerned to establish and maintain a national legislative, regulatory and organisational framework, specifying in particular the responsibilities of the various competent bodies, the programme for implementing management policies, the arrangements for the safety of management, a system for granting licences, appropriate measures for periods following the closure of repositories, the necessary financing mechanisms (including the sufficiency and availability of financial resources when the time comes) along with the provisions in terms of public information and participation. It also requires the establishment of integrated management systems including a guarantee of the quality, which give due priority to safety.

Under the terms of the Directive, each Member State concerned must also establish and update a national programme covering all steps of the management of irradiated fuel and radioactive waste, a programme that must in particular describe the management solutions proposed, RD&D activities, the cost estimates, the financing mechanisms, the responsibilities and timescales relating to the implementation of these solutions and the transparency policy with regard to the public.

Furthermore, in its grounds, the Directive clearly states that at this time, geological disposal is the safest and most sustainable solution for the long-term management of high-level waste and irradiated fuel considered as waste, storage, including long-term storage, remaining a temporary solution but not an alternative to disposal. Thus, Member States should provide for the planning and implementation of disposal solutions in their national policies for irradiated fuel and radioactive waste management.

Still in its grounds, the Directive also indicates that since the implementation process of disposal facilities will extend over several decades, maintaining flexibility and adaptability in the disposal programmes is generally considered necessary. To this end, reversibility and retrievability as operating and design elements may be used to guide the technical development of a disposal system. However, these elements should not be a substitute for a well-designed repository with a defensible basis for closure.

The Directive will have to be transposed into Belgian federal law within two years after it comes into effect. The Commission will have to be notified of the first national programme within a maximum period of four years after the Directive comes into effect (which is 23 August 2015 at the latest).

The ONDRAF/NIRAS Waste Plan is therefore a preparatory document for the Belgian national programme.

The solution for the long-term management of B&C waste recommended in the Waste Plan, if it is approved by a decision in principle, will help to satisfy several requirements of the "Waste" Directive, including the following:

- the national responsibility for management (Article 4.1);
- the establishment of a management policy (Article 4.1) that complies with the principles laid down in Article 4.3, particularly the consideration of the interdependencies between the various steps of irradiated fuel and radioactive waste generation and management (Article 4.3 (b)), the fact that long-term management is based on passive safety measures (Article 4.3 (c)), waste producers taking charge of the management costs (Article 4.3 (e)), and the establishment of an evidence-based and documented decision-making process (Article 4.3 (f));
- the disposal of radioactive waste on the territory of the Member State in which it was generated (Article 4.4);
- the establishment of a programme for implementing the management policy (Article 5.1 (a));
- the allocation of responsibilities between the organisations involved in the long-term management (Article 5.1 (f));
- the maintenance and further development of expertise and skills, as well as research and development activities to cover the needs of the programme for implementing the management policy (Article 8);
- the availability, when the time comes, of sufficient financial resources, taking due account of the responsibility of irradiated fuel and radioactive waste producers (Article 9);
- the opportunity for the public to participate in the decision-making process (Article 10.2).

The Waste Plan also serves as a preparatory document for the Belgian national programme provided for in Articles 11 and 12, in that this programme will have to describe, in particular, the management solutions proposed, RD&D activities, the cost estimates, the financing mechanisms, the responsibilities and timescales relating to the implementation of these solutions, and the transparency policy with regard to the public.

The long-term management solution recommended for B&C waste also relates to several of the grounds introducing the aforementioned Directive. Thus:

- radioactive waste, including irradiated fuel considered as waste, must be permanently confined and isolated from man and the biosphere. Its specific nature, namely that it contains radionuclides, requires arrangements to protect the environment and human health against dangers arising from ionising radiation, including disposal in appropriate facilities as the end location point. The storage of radioactive waste, including long-term storage, is only a temporary solution but not an alternative to disposal (Ground 21);
- it is broadly accepted that, technically, at this time geological disposal is the safest and most sustainable solution as a final step in the management of high-level waste and irradiated fuel considered as waste (Ground 23);
- reversibility and retrievability as design and operating elements can be used to guide the technical development of a repository. However, these elements should not be a substitute for a well-designed repository with a defensible basis for closure (Ground 23);
- each Member State has an ethical obligation to avoid any undue burden on future generations related to irradiated fuel and radioactive waste (Ground 24).

The answers to issues where the response is not a matter solely for ONDRAF/NIRAS must also, eventually, contribute towards greater compliance with the aforementioned requirements, and even conform with others. In particular:

- the establishment (or finalisation) by FANC of the regulatory frameworks specific to the safety of geological disposal of B&C waste and the long-term management of radioactive waste arising from remediation operations (and especially (very) low-level and long-lived waste), as well as legislation relating to interventions, will help to complete the regulatory framework in terms of the safety referred to in Article 5.1 (b);
- the clarification of the status of irradiated nuclear fuel from commercial reactors, as well as that of enriched fissile materials and plutonium-bearing materials, is a condition of establishing the national management policy required by Article 4.1;
- the answers to the related issues about the B&C waste inventory will help to satisfy the requirements of Article 12.1 (c).

A3 Definitions arising from the Belgian legal and regulatory framework

Closure: completion of all operations at some time after the emplacement of spent fuel or radioactive waste in a final storage facility. These operations include the final engineering or other work required to bring the facility to a condition that will be safe in the long term (Law of 2 August 2002, article 2)

Disposal (or final storage): emplacement of spent fuel or radioactive waste in an appropriate facility without intention to retrieve (Law of 2 August 2002, article 2)

Enriched fissile materials: any materials containing fissile isotopes of uranium in greater quantities than natural uranium and being found in a form other than that of fresh or irradiated fuel (RD of 30 March 1981, article 1)

Excess quantities: quantities of enriched fissile materials, plutonium-bearing materials or fresh or irradiated fuel for which no use or subsequent transformation is planned by the producer or operator (RD of 30 March 1981, article 1)

Inspection: operation performed when taking charge of waste or excess quantities and intended to verify its compliance with the specifications in force, in preparation for transferring responsibility (RD of 30 March 1981, article 1)

Intervention: human activity intended to prevent or reduce human exposure to ionising radiation from sources that are not part of a practice or are not under control, by acting on the ionising radiation sources, the exposure pathways and the people themselves (RD of 20 July 2001, article 2)

Orphan source: source where the level of activity when it is discovered is higher than the exemption level given in appendix IA and which is not under regulatory control, either because it has never been subject to such control or because it has been abandoned, lost, stolen or transferred to a new holder without notification in due form to the competent authority or without the recipient having been informed of it (RD of 20 July 2001, article 2)

Plutonium-bearing materials: any materials containing fissile isotopes of plutonium and being found in a form other than that of fresh or irradiated fuel (RD of 30 March 1981, article 1)

Practice: human activity likely to increase exposure of individuals to ionising radiation from an artificial or natural radiation source when natural radionuclides are processed for their radioactive, fissile or fertile properties, except in the event of emergency exposure (RD of 20 July 2001, article 2)

Radioactive substance: any substance containing one or several radionuclides, the activity or concentration of which cannot be ignored for radiation protection reasons (Law of 15 April 1994, article 1)

Radioactive waste: any material for which no use is foreseen and which contains radionuclides in concentrations in excess of those that the competent authorities consider permissible in materials suitable for use or discharge without control (RD of 30 March 1981, article 1)

Radioactive waste of foreign origin: radioactive waste that has obtained its radioactivity characteristics outside Belgium, except if this radioactivity is a result of equipment and/or waste of Belgian origin treated abroad (RD of 30 March 1981, article 1)

Source: radioactive substance, or device or facility able to emit ionising radiation or containing radioactive substances (RD of 20 July 2001, article 2)

Storage of plutonium-bearing materials and fresh fuel: temporary storage of these materials pending their subsequent potential use or classification as radioactive waste (RD of 30 March 1981, article 1)

Storage of radioactive waste: temporary storage of such waste with the intention and possibility of subsequent recovery (RD of 30 March 1981, article 1)

Storage of irradiated fuel: temporary storage of these materials pending reprocessing or their classification as radioactive waste (RD of 30 March 1981, article 1)

Taking charge: set of technical and administrative operations for collection of radioactive waste or excess quantities from producer sites and their transfer to the facilities managed by the Organisation (RD of 30 March 1981, article 1)

Treatment and conditioning of radioactive waste: series of mechanical, chemical, physical and other operations designed to convert radioactive waste into packages that satisfy operational requirements for handling, transport, storage or disposal (RD of 30 March 1981, article 1)

Irradiated fuel: fissile or plutonium-bearing materials contained within a structure that allows their use in a reactor, after their definitive unloading from the reactor (RD of 30 March 1981, article 1)

Work activity: an activity that is not a practice, but which implies the presence of natural ionising radiation sources and which is likely to lead to a notable increase in human exposure, not negligible from the point of view of protection against ionising radiation (RD of 20 July 2001, in accordance with article 1)

A4 Acronyms

ALARA	As low as reasonably achievable (taking into account economic and societal factors)
Andra	*Agence nationale pour la gestion des déchets radioactifs* (National Agency for Radioactive Waste Management) (France)
CEA	*Commissariat à l'énergie atomique et aux énergies alternatives* (Atomic Energy and Alternative Energies Commission) (France)
CNE	*Commission nationale d'évaluation* (National Review Board) (France)
COGEMA	*Compagnie générale des matières nucléaires* (General Company for Nuclear Materials — which became AREVA NC) (France)
CoRWM	Committee on Radioactive Waste Management (United Kingdom)
COVRA	*Centrale Organisatie Voor Radioactief Afval* (Central Organisation for Radioactive Waste) (Netherlands)
EDRAM	International Association for Environmentally Safe Disposal of Radioactive Materials
EIA	Environmental Impact Assessment
EIG	Economic Interest Grouping
FANC/AFCN	*Federaal Agentschap voor Nucleaire Controle / Agence fédérale de Contrôle nucléaire* (Federal Agency for Nuclear Control) (Belgium)
FSC	NEA Forum on Stakeholder Confidence
HADES	High-Activity Disposal Experimental Site
IAEA	International Atomic Energy Agency (United Nations)
ICRP	International Commission on Radiological Protection
IRE	*Institut national des radioéléments* (National Radioelements Institute) (Belgium)
IRMM	Institute for Reference Materials and Measurements (European Union)
KASAM	Swedish National Council for Nuclear Waste (Sweden)
MONA	*Mols Overleg Nucleair Afval* partnership (Belgium)
MOX	Mixed-Oxide Fuel
Nagra	*Nationale Genossenschaft für die Lagerung radioaktiver Abfälle* (National Cooperative for the Storage of Radioactive Waste) (Switzerland)
NEA	OECD Nuclear Energy Agency
NORM	Naturally Occurring Radioactive Materials

OECD	Organisation for Economic Cooperation and Development
ONDRAF/NIRAS	*Organisme national des déchets radioactifs et des matières fissiles enrichies / Nationale instelling voor radioactief afval en verrijkte splijtstoffen* (National Organisation for Radioactive Waste and Enriched Fissile Materials) (Belgium)
OVAM	*Openbare Vlaamse Afvalstoffenmaatschappij* (Public Waste Agency of Flanders) (Belgium)
RD	Royal Decree
RD&D	Research, Development and Demonstration
SAFIR	Safety Assessment and Feasibility Interim Report
SCK•CEN	*Studiecentrum voor Kernenergie / Centre d'Etudes de l'Energie Nucléaire* (Nuclear Research Centre) (Belgium)
SEA	Strategic Environmental Assessment
SFC	Safety and Feasibility Case
SKB	Swedish Nuclear Fuel and Waste Management Company (Sweden)
SPRI	*Service de Protection contre les radiations ionisantes* (Protection Service against Ionising Radiation) (Belgium)
STORA	*Studie- en Overleggroep Radioactief Afval Dessel* partnership (Belgium)
TENORM	Technologically Enhanced, Naturally Occurring Radioactive Materials
tHM	ton Heavy Metal
UKAEA	United Kingdom Atomic Energy Authority (United Kingdom)
VUB	*Vrije Universiteit Brussel* (Free University of Brussels) (Belgium)
WIPP	Waste Isolation Pilot Plant (United States)

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