French National Plan for the Management of Radioactive Materials and Waste (PNGMDR)

2010 – 2012

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Ministère
de l'Écologie,
de l'Énergie,
du Développement
durable
et de la Mer

AUTORITÉ
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FOREWORD

Radioactive materials and waste must be sustainably managed for the protection of human health, safety and the environment. In addition, it is essential that burdens imposed on future generations be limited.

The French National Plan for the Management of Radioactive Materials and Waste (PNGMDR) is a privileged tool for the implementation of these principles over time under a the legally devised framework. The purpose of the PNGMDR is to draw up a regular assessment on the radioactive substance management policy, evaluate the new needs and determine the objectives to be attained in the future, notably in terms of research and studies. The strength of the PNGMDR is its exhaustiveness : it covers both ultimate waste and reusable radioactive materials, both existing management routes and those planned or to be defined, both high level radioactive waste and lower level radioactive waste, and even waste not strictly speaking considered to be radioactive.

The reader will notice that the PNGMDR structure and perimetry has evolved since the version 2006. We have strived to take into account comments formulated about the previous PNGMDR version, notably those of the Parliamentary Office for Evaluation of Scientific and Technological Options, and the National Evaluation Committee. Points related to reusable materials were particularly completed. This PNGMDR could still be improved on in the future ; all reader sugmanagements on the matter will of course be appreciated.

Despite the management framework set up in France, radioactive waste still too often gives rise to fear and disproportionate reactions. To instill confidence, transparency and information are crucial. Likewise, dialogue and consultation, notably with civil society representatives, must also from now on be decisive for the elaboration of public policies.

For the sake of consultation, the Government and ASN decided to rewrite the PNGMDR based on the presentations and exchanges made within a pluralistic working group, bringing together environmental protection associations, representatives of elected officials, and control and evaluation authorities besides the traditional radioactive waste producers and managers. We take this opportunity to warmly thank all the participants in this working group for their contribution, whose quality must be praised, and without which the progress made to date would not have been achievable in such a few years.

For transparency, and in conformity with the law, the PNGMDR will be rendered public and disseminated on the Internet sites of the Nuclear Safety Authority (ASN) and the General Directorate for Energy and Climate (DGEC). A more informative and educationally oriented summary will also be published in order to make it accessible to the largest number of people.

The PNGMDR proposes ways to improve the management of all the radioactive materials and waste. These proposals are the result of a significant amount of work engaged since the publication of the previous PNGMDR in 2006, notably the performance and then evaluation of the studies requested by the Government. Although the progress made has been considerable, the work must continue to be pursued. It should be noted that, in application of the principle of pollutant/payer, all this work will continue to be funded directly or indirectly by the producers of radioactive materials and waste.

Although radioactive materials and waste are today safely under the control of ASN, an independent authority, we cannot overemphasize to what extent the implementation of the recommendations presented in this PNGMDR seems indispensable. It is of high importance not only to meet the objectives and timetables fixed by the Parliament in 2006, but also and above all to advance further in the sustainable management of radioactive materials and waste by defining final long-term management routes for all these substances. It is our responsibility to assume this obligation today in order to avoid transferring undue burdens to future generations.

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(DGEC)

André-Claude Lacoste
President of the Nuclear Safety Authority
(ASN)

INTRODUCTION

Faced with the high diversity of radioactive materials and waste, it may be difficult to grasp the relevance and consistency of the installed management framework. The purpose of the National Plan for the Management of Radioactive Materials and Waste (PNGMDR) is to clarify this management framework and improve it. To this end, it draws up an assessment of the management policy, evaluates the needs and determines the objectives to be attained in the future.

The PNGMDR's usefulness was confirmed by Parliament. The evaluation report of the PNGMDR 2007-2009 by the Parliamentary Office for Evaluation of Scientific and Technological Options thus indicates that "the interest of a summary document exposing all the problems and the solutions related to the management of radioactive waste was underlined a number of times by the Office […]. Since such a plan can allow achieving exhaustiveness and introducing a consistency in the management of radioactive waste, the Office deemed it necessary that it be linked to the law in one way or another. […] Conforming to the Office's recommendations, the Act of 28 June 2006 related to the sustainable management of radioactive waste stipulated that such a plan must be elaborated, updated every three years and published, extending its scope to reusable radioactive materials […]."

Thus, the PNGMDR provides the public with a global vision of the management of radioactive materials and waste, concerning both topics "in the news" and those less publicised. Some waste, in fact, attracts momentarily particular attention, for example, on the occasion of a search for a disposal site, such as in 2008-2009, for so-called low level and long lived ("LL-LL") waste. The media also broadcast in 2008 and 2009 special enquiries on the management of mining residues and on reprocessed uranium ; all these topics are discussed in detail in the PNGMDR. Other waste topics attract less attention, such as sealed radioactive sources, which are more dispersed throughout France, and for which the improvement of management is dealt with in this document. A key interest of the PNGMDR is thus its exhaustiveness.

Article 6 of the Act of 28 June 2006 related to the sustainable management of radioactive materials and waste defines more precisely the PNGMDR's objectives : the PNGMDR "draws up the assessment of the existing management methods for radioactive materials and waste, reports on the estimated needs of storage and disposal facilities, specifies the capacities necessary for these facilities and the storage times, and determines the objectives to be attained for radioactive waste for which there is still no final management method available". This article also states that "the national plan organises the implementation of research and studies on the management of radioactive materials and waste by setting timetables for the implementation of new management methods, creating facilities or modifying existing facilities […]", and that '"it contains in the annex a summary of the achievements and research conducted in foreign countries".

The document is broken down into three main parts. Part one reviews the principles and the objectives of the management of radioactive materials and waste, including an overview of the legal and institutional framework. An assessment of the existing management methods or those envisioned at the end of 2009 is then drawn up. Part three presents recommendations to improve the management of radioactive materials and waste, whether these materials and waste benefit today from final management routes or not. Several annexes are included : a summary of the achievements and research conducted in foreign countries ; a precise evaluation of the needs in storage facilities ; and a detailed presentation of the research and studies to be conducted in the upcoming years on the management of radioactive materials and waste.

The management of radioactive materials and waste : principles and objectives

1.1. Overview of radioactive materials and waste

A few scientific concepts about radioactivity

Radioactivity is a natural physical phenomenon during which unstable atomic nuclei are transformed after a series of disintegrations into stable atomic nuclei. These reactions are accompanied by a release of energy, mainly in the form of "three types of radiation" :

- "alpha" radiation, which corresponds to the emission of helium 4 nuclei (2 protons + 2 neutrons) ; in external irradiation, a simple sheet of paper is sufficient to stop it from propagating ;
- "beta" radiation, which corresponds to the emission of electrons (or equivalent positive charged particles); in external irradiation, an aluminium foil is sufficient to stop them ;
- "gamma" radiation, which corresponds to electromagnetic radiation (such as visible light or X rays, but of higher energy) ; in external irradiation, concrete or lead screens protect against such radiation.

Radioactive waste is highly diversified ; some may be dangerous, but this dangerousness is not linked to the waste's radioactive nature (chemical toxicity, for example). Two main characteristics allow classifying waste from the viewpoint of radioactivity :

- the "activity" of the radioactive elements contained in the waste, which corresponds to the number of disintegrations per time unit (in other words, the "level" of radioactivity of the radioactive elements) ; the unit generally used to measure the activity of waste with respect to its mass is the becquerel per gramme (Bq/g) ;
- the "half-life" of the contained radioactive elements, which corresponds to the time it takes for half of the number of atoms of a radioactive element to disintegrate. The half-life varies with each radioelement's characteristics (110 minutes for argon 41 ; 8 days for iodine 131 ; and 4.5 billion years for uranium 238). No external physical action is able to modify the half-life of a radioactive element, except by a transmutation (transformation from one radioactive element to another under the action of neutrons). After 10 half-lives, an element's level of radioactivity is divided by approximately 1000 ; generally, this duration of 10 half-lives represents the considered element's "lifetime".

1.1.1. Definition of radioactive materials and waste

Legally speaking, the Environmental code (art L.542-1-1) states that "a radioactive substance is a substance which contains natural or artificial radionuclides whose activity or concentration justifies a radiological protection control". In practice, there are not unique activity or concentration thresholds valid for all radionuclides which would allow determining whether a radiological protection control is justified.

In the case of natural materials, most of the international recommendations and national regulations retain an approach based on the activity concentration per mass compared to the average observed in the world.

In the case of artificial radionuclides, the radiological protection control is considered to be unnecessary for materials used in limited quantities (typically less than one tonne), whose activity per mass (in Bq/g) and the total activity (in Bq) are less than the "exemption threshold" values. In addition, there are accumulation rules and total activity limits which guarantee that, in the case of a significant accumulation of many sources which are all exempted, the activity is subject to an authorisation from the viewpoint of radiological protection. Thus, the exemption corresponds to the initial decision to avoid imposing a radiological protection control when it is not necessary.

Another important concept is release, namely, the withdrawal of a material from the regulated field. There are various approaches, depending on the countries, to release the uses of radioactivity from the regulated field. Some countries implement release thresholds expressed in activity per mass (Bq/g) which are either universal (regardless of the material, its origin and destination) or dependent on the material, its origin and destination. These thresholds can be lower than the exemption thresholds ; they cannot be higher for a question of logic. France has developed a different approach since it is assumed that any material covered the regulations on radioactivity uses (that is, used in the framework of a nuclear activity in the sense of the regulations) must be considered to be radioactive from the moment it might have come in contact with radioactive contamination or might have been activated by radiation. The French doctrine does not provide for an unconditional release of very low level waste on the basis of universal thresholds. This leads to a special management of this waste and its elimination in a dedicated disposal.

Among radioactive substances, some are considered to be reusable materials and other as waste and, if necessary, ultimate waste.
The general scope of the concept of waste taken in a broad sense is set by the Environmental code (art. L. 541-1) : waste is "any residue originating from a production, transformation or utilisation process, any substance, material, product, or more generally, any movable commodity abandoned or that its holder intends to abandon". Moreover, "is considered ultimate (…) a waste resulting or not from the reprocessing of a waste, which is no longer liable to be processed under the technical and economic conditions of the moment, notably by extraction of the reusable part or by reduction of its polluting or dangerous nature".
For radioactive materials and waste, the Environmental code was completed by the definitions given in article 5 of the Act of 28 June 2006 on the management of radioactive materials and waste : "a radioactive material is a radioactive substance for which a future use is foreseen or considered, if necessary after reprocessing. Radioactive waste is radioactive substances for which no future use is foreseen or considered. Ultimate radioactive waste is radioactive waste which can no longer be processed under the technical and economic conditions of the moment, notably by extraction of its reusable part or by reduction of its polluting or dangerous nature."

1.1.2. Origin of radioactive materials and waste

Radioactive substances can occur naturally or be the consequence of human activities without it being easy to define the boundary between these two origins. For example, in the case of enhanced natural radioactivity, some natural materials can be used by man in such a way that it leads to a concentration of radioactivity without, however, their radioactive properties being used.

There are many natural ionising radiation sources : ores and materials containing radionuclides naturally present in our environment (isotopes of uranium and thorium, tritium, potassium 40, carbon 14, or affiliated elements, such as radium and radon), cosmic radiation, etc. These natural radionuclides present in the environment are dispersed throughout all of the biosphere compartments. In addition, the radionuclide concentration is extremely variable depending on the material and its origin : exposure to radionuclides of a natural origin can vary more than one order of magnitude according to the regions in the world (from 2.4 mSv/year as an average in France to more than 50 mSv/year in some parts of India or Brazil).

In addition, since the beginning of the 20th century, human activities involving the handling of radioactive substances have produced radioactive materials and waste, which originate from five main economic sectors :

- Electronuclear sector : mainly, nuclear power plants producing electricity, plants of the fuel cycle front end (extraction and reprocessing of the uranium ores, conversion, enrichment and fabrication of the fuel), and spent fuel reprocessing plants ;
- Defence sector : mainly, activities linked to the deearthnt force and the nuclear propulsion of certain ships, including some research activities ;
- Research sector : civil nuclear research activities ;
- Non-electronuclear industry sector : notably, extraction of rare earths, fabrication and utilisation of sealed radioactive sources ;

- Medical sector : therapeutic, medical diagnostic and medical research activities.

The sectors which have historically contributed the most to production of radioactive waste in France are the Electronuclear, Research and Defence sectors (cf. section 1.1.4 dealing with the inventory of radioactive materials and waste).

1.1.3. Usual classification of radioactive materials and waste

In conformity with the definitions prescribed in this section 1.1, the following distinction can be made : on the one hand, radioactive materials, for which a future utilisation is foreseen or considered, and, on the other hand, radioactive waste, for which no future utilisation is foreseen or considered.

Radioactive materials are not subject to a specific classification. Radioactive materials are essentially uranium (natural, enriched or depleted), fuels (being used or spent), uranium and plutonium separated by reprocessing spent fuels, and reusable materials originating from industries other than the electronuclear industry (mainly materials containing thorium).

For radioactive waste, the usual French classification is based on two key parameters in order to define the appropriate management method : the level of activity of the contained radioactive elements and their half-life. This classification consists of the following main categories :

- High Level (HL) waste, mainly constituted of packages of vitrified waste originating from spent fuels after reprocessing. These waste packages concentrate the greatest part of the radionuclides, that is, either fission products or minor actinides. This waste has a level of activity on the order of several billion Bq per gramme.

- Intermediates Level and Long Lived (IL-LL) waste, also mainly originating from spent fuels after reprocessing and the operation and maintenance activities of reprocessing plants. This waste consists of cladding waste, hulls and end-caps comprising the nuclear fuel clad, conditioned in cemented or compacted waste packages, as well as technological waste (spent tools, equipment, etc.), waste originating from the processing of effluents, such as bituminised sludge. This waste has an activity on the order of one million to one billion Bq per gramme.

- Low Level and Long Lived (LL-LL) waste, essentially graphite waste and radium-bearing waste. The packages of graphite waste, originating mainly from the dismantling of the uranium natural graphite gas reactor, have an activity on the order of magnitude of ten thousand to one hundred thousand Bq per gramme. The long-term activity is essentially due to the long-lived beta-emitting radionuclides. Radium-bearing waste, originating mostly from non nuclear industrial activities (such as the processing of ores containing rare earths), consists of mainly long-lived alpha-emitting radionuclides and has an activity of a few tens of Bq per gramme to several thousand Bq per gramme.

- Low or Intermediate Level and Short Lived (LL/IL-SL) waste, originating mainly from the operation and dismantling of nuclear power plants, fuel cycle facilities, research centres and to a lesser extent from biomedical research activities. This waste has an activity of a few hundred Bq per gramme to one million Bq per gramme.

- Very Low Level (VLL) waste, mainly originating from the operation/maintenance and dismantling of nuclear power plants, fuel cycle facilities and research centres. This waste has a level of activity generally below 100 Bq/g.

This classification allows schematically associating to the various waste categories long-term management routes, which will be described in more detail in the following sections. They are summarised in the table below.

<table>
<tr><th></th><th>Very Short Lived
(half-life < 100 days)</th><th>Short Lived
(half-life ≤ 31 years)</th><th>Long Lived
(half-life > 31 years)</th></tr>
<tr><td>Very Low Level
(VLL)</td><td rowspan="3">Management by radioactive decay on the production site

then elimination in conventional management routes</td><td colspan="2">Surface disposal
(Aube disposal centre of very low level waste)</td></tr>
<tr><td>Intermediate Level
(IL)</td><td></td><td></td></tr>
<tr><td>High Level
(HL)</td><td colspan="2">Deep repository (under study in compliance with the act of 28 June 2006)</td></tr>
</table>

It should be noted that there is no unique classifying criterion to determine a waste's category : in addition to a waste's global activity, it is necessary to study the radioactivity of each of the radionuclides present in the waste.
Moreover, this classification, which is based only on the level of activity and the half-live of the radionuclides contained in the waste, is not sufficient to determine precisely the appropriate management method for a particular type of waste. The physical and chemical characteristics of the waste, as well as it origin, must, in fact, also be taken into account.

1.1.4. Summary of the national inventory of radioactive materials and waste

In conformity with the provisions of the Act and regulations detailed in section 1.3.1, a national inventory of the radioactive materials and waste is elaborated, updated and published every three years by the National Agency for Radioactive Waste Management (Andra).

Published in June 2009, the national inventory 2009[1] presents the materials and waste stocks at the end of 2007, as well as the forecasts until the end of 2020 and the end of 2030, and after the end of the lifetime of the existing facilities[2]. This inventory also presents the storage capacities for HL, IL-LL, LL-LL waste containing radium and tritium, as well as the storage needs for HL and IL-LL waste pertaining to the deep repository. Finally, the inventory presents radioactive material stocks, the sites polluted by radioactivity and information about the mining residue disposal sites[3].

For radioactive waste, the assessments at the end of 2007 and until the end of 2020 and end of 2030, as well as the assessment of the "engaged" waste, are presented below for each management route. The radioactive waste quantities are indicated in equivalent conditioned m^3 (waste volume once it is conditioned).

(in equivalent conditioned m³)	**EXISTING VOLUMES** at the end of **2007**	**EXISTING VOLUMES** until the end of **2020**	**EXISTING VOLUMES** until the end of **2030**	**"ENGAGED" WASTE**[4]

1 Available on www.andra.fr
2 Existing reactors, EPR being built at Flamanville, the plant at La Hague, CEA civil and defence facilities, etc.
3 The associated mining mining and residue sites are presented in the MIMAUSA inventory updated by IRSN.
4 Electronuclear production pursuit scenario

IL-LL	41 757	46 979	51 009	65 300
LL/IL-SL	792 695	1 009 675	1 174 193	1 530 200
VLL	231 688	629 217	869 311	1 560 200
TOTAL	**1 150 969**	**1 804 142**	**2 251 449**	**3 328 310**

Note : The HL waste volumes include 74m^3 of spent fuels. At the end of 2007, the radioactive waste management solution of 1 564 m^3 remains to be defined either because the waste is in a physical or chemical form which does not allow it to be associated with an existing or planned management route, or because no reprocessing method is envisioned for the moment. For the sake of consistency with the 2009 national inventory of radioactive materials and waste, it was decided to reuse this inventory's estimations for the estimated volumes until the end of 2020 and 2030. These estimations contain a large number of significant figures due to the adopted methodology. Future waste volumes of course cannot be naturally anticipated to within a m^3 particularly because some conditioning modalities shall be subsequently prescribed.

The distribution of the radioactive waste volume at the end of 2007 per management route is thus indicated in Figure 1.

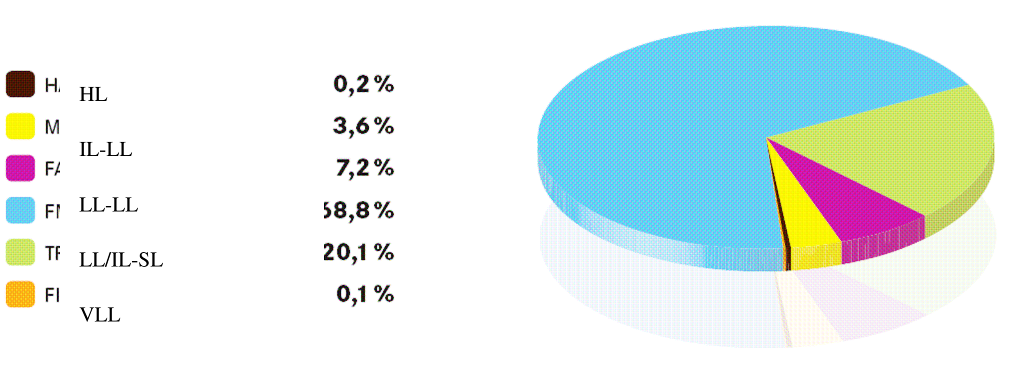


Figure 1. Radioactive waste volumes at the end of 2007 per management route in equivalent conditioned m3

These quantitative assessments do not take into account :

- the uranium ore processing residues definitively disposed of on the spot[5] ;
- the "historically disposed of" waste dispersed over 23 sites - except for mining sites. On these sites, waste which is not under Andra's responsibility is definitively disposed of. Thus, there are 12 listed sites corresponding to the disposal of conventional waste, 8 sites generally in the proximity of nuclear facilities or plants where radioactive waste was disposed of in the past in mounds, backfills and lagoons, as well as 3 French Polynesia sites (Mururoa, Fangataufa and Hao) on which the waste originating from nuclear experiments in the Pacific were disposed of ;

HL
IL-LL
LL-LL
LL/IL-SL
VLL
Management route to define

- the radioactive substances located on sites which accommodated activities using the radioactivity and which are no longer problematic and do not require any "clean-up" ;

[5] The associated mining and residue sites are presented in the MIMAUSA inventory updated by IRSN

- the waste immersed in the Atlantic in 1967 and 1969 ;
- very short lived waste with a half-life less than 100 days managed by decay on the production site before elimination through conventional management routes.

HL waste, although it represents only 0.2% of the total volume as indicated in Figure 1, concentrates, however, 95% of the radioactivity (cf. Figure 2).

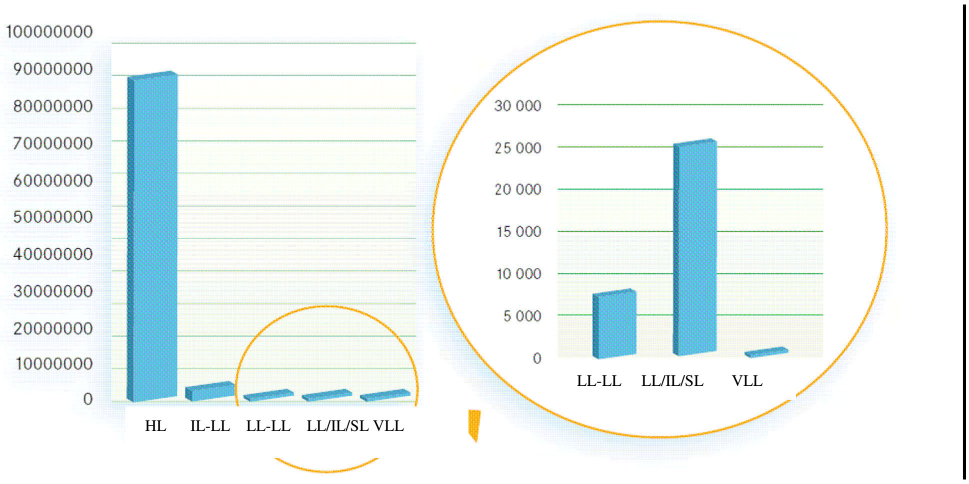


Figure 2. Distribution of the radiological activity at the end of 2007 in TBq (that is, 10^{12} Bq)

The economic sectors mainly responsible for the production of radioactive waste are the Electronuclear, Defence and Research sectors. However, the respective part of each of the sectors depends very much on the type of considered waste : examples of HL and VLL waste are shown in Figure 3 and Figure 4.

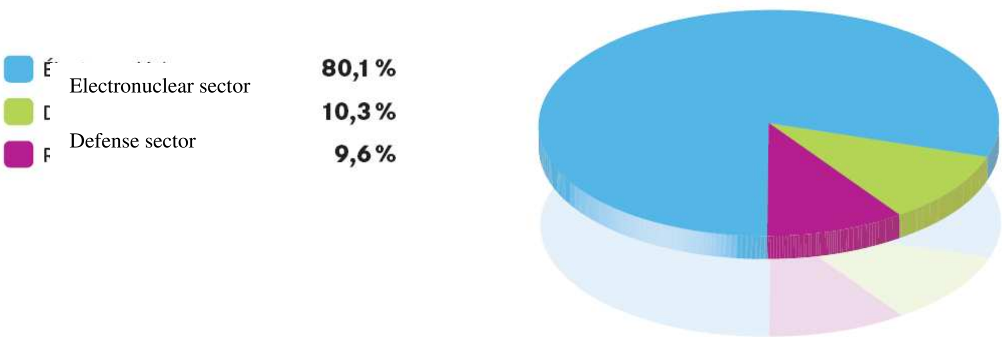
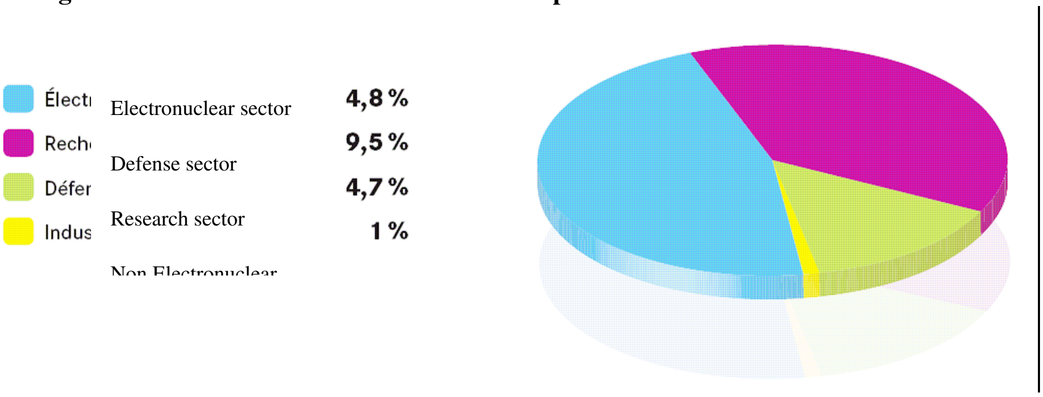


Figure 3. Distribution in volume of HL waste per economic sector at the end of 2007



The main owners of radioactive waste in alphabetical order are AREVA, CEA, and EDF. However, here again, the respective parts of these owners vary according to the type of considered waste (cf. Figure 5 and Figure 6).

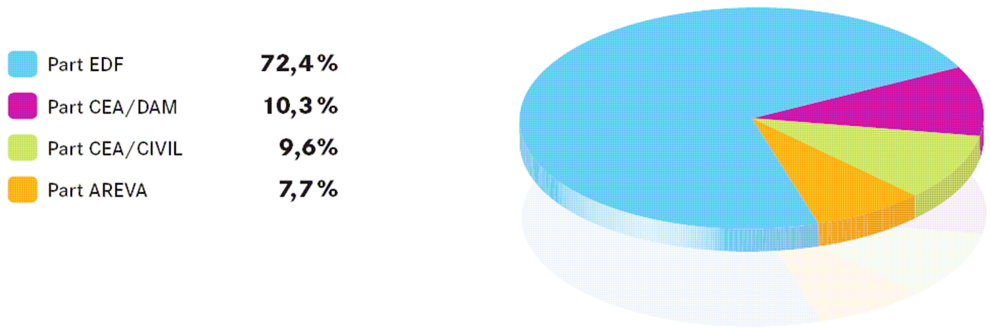


Figure 5. Distribution in volume of HL waste per French owner at the end of 2007

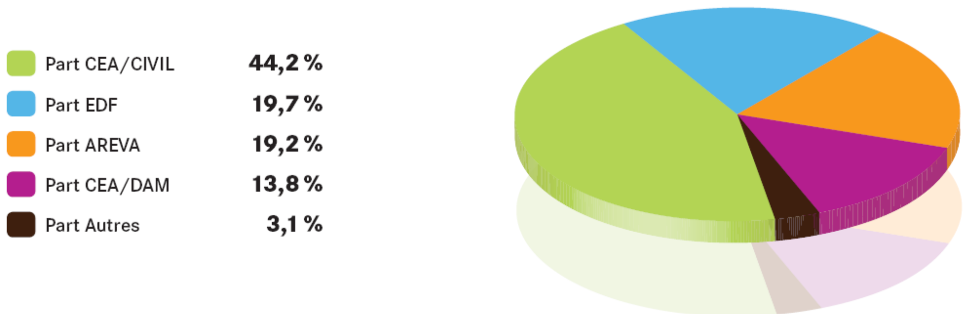


Figure 6. Distribution in volume of VLL waste per owner at the end of 2007

For **radioactive materials**, the table below lists the quantities declared at the end of 2007, as well as the forecasts until the end of 2020 and end of 2030.

		End of 2007	End of 2020	End of 2030
Natural uranium extracted from the mine (in tML)		27 613	32 013	32 013
Enriched uranium (in tML)		3 306	1 764	2 714
Uranium originating from spent fuels after reprocessing (tML)		21 180	36 000	49 000
Depleted uranium (tML)		254 820	332 324	452 324
Thorium (t)		9 399	9 399	9 290
Suspended matter (t)		21 672	0	0
Fuels being used in electronuclear power plants and in research reactors (tML)	UOX	4 500	3 860	1 100
	URE	80	290	0
	MOX	290	440	0
	Research	5		
Spent fuels awaiting reprocessing	UOX (tML)	11 504	13 450	11 000
	URE (tML)	251	1 020	1 320
	MOX (tML)	1 028	2 320	2 550
	RNR (tML)	104	104	104
	Experimental fuels (t)	42	0	0
	National Defence fuels	141	230	298
Plutonium originating from spent fuels after reprocessing (tML)		82	55	53

Note : Here again, it was decided to reuse the estimations of the 2009 national inventory for the estimated volumes for the end of 2020 and 2030. These estimations contain a large number of significant figures due to the adopted methodology. The estimated material volumes until 2020 and 2030, however, cannot naturally be anticipated to within a m^3.

1.2. *The principles to take into account to define the management routes*

Radioactive waste must be managed according to the following principles inspired from the general legislation on waste management (chapter 1 of title IV of book V of the Environmental code, derived from the Act no. 75-633 of 15 July 1975 modified, related to the elimination of waste and the recovery of materials) :

- it is necessary to prevent and reduce at the source, wherever reasonably possible, the production and harmfulness of waste, notably by an appropriate waste sorting and segregation ;
- the strategy of confinement/concentration must be privileged, even though in some cases it may be exceptionally allowed to not apply it if such non-application is justified ;
- waste transports are organised in order to limit the transported waste volumes and the travelled distances within the scope of a given management strategy ;
- production from waste by reusage or recycling must be favoured, provided this production does not prove detrimental to public health or the environment ;
- the public must be informed about the effects on public health and the environment from long-term waste production and management operations.

To define long-term management routes for radioactive waste, it is important to take into account a principle of proportionality with respect to risk and impact, and a principle of optimisation between costs (financial, human, etc.) and benefits expected from the implementation of a precise management route. This principle is difficult to be simply applied, particularly because it requires considering the costs and benefits over different time periods sometimes very far in the future.

1.2.1. Very varied management methods for also very varied waste

A classification of radioactive waste was retained in the decree of 16 April 2008 setting the prescriptions related to the PNGMDR. This classification identifies according to the nature of the waste (activity and lifetime) the final management route retained or considered (cf. 1.1.3).

In practice, this classification leads to distinguishing very low level (VLL) waste, on the one hand, and low, intermediate or high level waste (LIHL) waste, on the other hand. VLL waste has a very low radiotoxicity ; contact with it rarely presents an immediate sanitary risk. Higher level waste can induce on contact the maximum allowable annual dose for the public in a short time, or when ingested in small quantities, which necessitates taking measures at least in terms of isolation and remote placement of the waste, and taking handling precautions. Thus, for ultimate high or intermediate level and long lived waste originating from the current installed base (notably, vitrified fission products and minor actinides), an almost unanimous consensus was reached with the experts at the international level after fifteen years of research, namely, the geological repository constitutes a safe and sustainable management route.

The classification does not take into account some degrees of complexity. For example, nuclear industry's operational waste, even though it generally contains to a very large extent short lived radionuclides, also often contains traces of long lived radionuclides, which must be taken into account in the safety analysis of a repository. Likewise, the differentiation between VLL and higher level waste based on the immediate radiological impact in the case of a general-purpose utilisation is too simplifying from the viewpoint of long-term management routes for which many other parameters must be taken into account, such as toxicity and chemical reactivity. Moreover, a waste can be classified in a defined category, but may not be accepted in the corresponding management route due to other characteristics (stability, presence of some chemical elements, such as niobium used in an alloy with zirconium for fuel rod envelopes). As a result, the waste category is not necessarily comparable to its management route.

In addition, identifying the relevant management routes to other criteria must be taken into account : possible necessity of a storage (management route retained for the most radiotoxic waste pending reprocessing and ultimate radioactive waste awaiting disposal) ; existence of an identified and solvent waste producer ; management routes retained in the past for some waste categories not always conforming to today's regulatory requirements, but on which it is not always relevant to intervene. Moreover, some waste categories necessitate taking into account their own parameters. This is true for disused sealed radioactive sources which, considering their specificity (attractiveness, size, etc.), call for other parameters than simply activity and lifetime criteria (the modalities proposed for their management are detailed in the following sections) for their management.

Specific management must also be defined in case the owner of an object is not aware that it is a radioactive waste. This is true, in particular, for historical radioactive objects kept by private individuals or small communities (educative kits, objects with radium, lightning rods, etc.) and sometimes unknown to them. In this case, the first step is for the owner to become aware of the situation. A public subsidy will take care of this free of charge or significantly fund dealing with radioactive objects. Andra services handle requests according to two criteria : the holder's status and the nature of the objects. The subsidy is reserved in order of priority to private individuals and to public safety services (fire departments, gendarmerie, etc.), rural communities and educational institutions. Above a certain sum, which corresponds to a stock of several objects, funding is decided on a case by case basis by the National Funding Commission for Radioactive Matters (CNAR)[6].

Since the main objective of the PNGMDR is to work on the identification and implementation of management routes for all the produced waste, the current classification offers for most of the produced radioactive waste a simple indication of the various waste and identifes the available processes even though it does not give an exhaustive vision of all the management routes.

1.2.2. A large number of parameters to be optimised for each management method

The optimisation of a waste management route, when it exists, must be unceasingly searched. Several criteria must thus be taken into account, and here are the main ones.

Reducing the volume of waste to be disposed of

Radioactive waste disposals are rare resources presenting limited capacities and, therefore, they should be preserved only for the disposal of ultimate radioactive waste. The policy in force in terms of waste management provides for the elaboration by the waste producer of a so-called "waste study" which integrates this objective. This study must contain a waste zoning map, which distinguishes between nuclear waste zones and conventional waste zones, to ultimately allow lowering the waste production. This assumes, however, that the reduced entry of materials and equipment in a nuclear waste zone is sufficiently studied to allow reducing the quantity of produced waste.

Radioactive waste management must, therefore, begin with some measures taken at the source on the site itself of the waste producer. Sorting operations are the first step in the reduction of the produced waste volume. They allow separating the waste according to its characteristics, notably the half-life of the radionuclides contained in it. Sorting precedes reprocessing operations before the waste is conditioned. Processing techniques vary according to the nature of the waste, which may be compacted (solid radioactive waste), incinerated or melted (liquid radioactive waste). Created in 1999, the Centraco plant (Nuclear Processing and Conditioning Centre) processes low level liquid waste originating from research centres and small producers such as hospitals. This facility is contributing to the reduction of waste volumes addressed to the very low level waste disposal centre. The PNGMDR can only encourage, therefore, producers to pursue their already engaged efforts in the evolution of processing solutions and conditioning methods to reduce waste volumes[7].

Some reflective thinking on the materials introduced in the waste is also worthwhile. For example, it may allow limiting the entry of too much organic waste (such as vinyl pockets for conditioning), whose processing has proven difficult and is liable to pose problems for the disposal of some waste.

Another orientation of progress contributing to the reduction of waste to be disposed of consists of reusing a part of the produced waste. Initiatives have been taken or are planned by some operators for metals and are described in section 3.3.1. of this report. Management routes are evidently more difficult to set up since they assume a reusage in the nuclear sector, according to the French doctrine (in consistency with the lack of a release threshold ; in particular, see section 1.2 in the annex giving regulatory information).

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6 The CNAR is presided by Andra's female Chief Executive Officer and includes the representatives of the trustee ministries (DGEC, DGPR, DGS), ASN, IRSN, the French Association of Mayors, the environmental defence associations, qualified personalities. Andra is in charge of the CNAR secretariat.

7 See the chapter related to evolutions since 2006 in the national inventory of radioactive materials and waste of the Andra-Edition 2009.

Anticipating needs in processing and storage facilities

Time is a crucial criterion in the implementation of long-term management routes to find an appropriate adequacy between the needs in storage, processing/conditioning, characterisation and transport facilities and the resources available at time t. Moreover, the integration of this factor t allows anticipating the risks linked to the failure of the waste producer. The volume and the availability of long-term management routes with respect to needs must be monitored and anticipated so that the waste production does not induce needs which would be higher than the available and authorised capacities.

To this end, the definition by waste producers of a intermediate- and long-term management strategy for their waste seems an indispensable tool to allow them individually or in connection with other producers to define their present and future needs for each of the waste management stages and to acquire the resources (storage, packaging and transport facilities, characterisation means, etc.) which are indispensable for an optimised management. These strategies are regularly examined by safety authorities supported by IRSN. The High Committee for Transparency and Information on Nuclear Safety (HCTISN) also performs a monitoring function, which it shares with Local Committee on Information (CLIs) and National Association of CLIs (ANCLI).

Talking about future waste, such as the waste originating from the operation of the ITER facility or the waste originating from the operation of an installed base of fourth generation nuclear reactors, its management should be examined with respect to existing solutions in order to demonstrate its compatibility or to define the necessary evolutions of the solutions, or possibly the creation of new solutions (compatibility with disposal specifications, management of volatile elements, in particular, iodine, new conditioning processes associated with pyrochemical reprocessing, consequences on the disposal's surface footprint, etc.).

To this end, the National Plan for the Management of Radioactive Materials and Waste (PNGMDR), described more in detail in the section 1.3.2 constitutes a useful anticipation, planning and coordination tool : it aims notably at making an assessment of the existing radioactive materials and waste management methods, recording the estimated needs in storage and disposal facilities, specifying the necessary capacities as well as the storage durations, and determining the objectives to be attained for radioactive waste for which there is still not any final management method.

Optimising the confinement of waste to guarantee the safety of its management

The purpose of fabricating a package is to confine waste in a stable, solid and monolithic form. Sometimes, it is necessary to process it before conditioning to ensure a compatibility, notably a physico-chemical compatibility, between the waste and the matrix or the immobilising system retained for the package's configuration. The main matrices industrially used and implemented for many years are notably glass and cement. For some solid waste, the compacted slabs (hulls and end-caps) are stacked directly in the container. Upcoming studies in the near future will be aimed at making these processes more industrially high-performance oriented either by increasing their production capacities, or by extending their fields of application to new waste, or by developing new matrices to optimise the confining properties of some packages.

Searching for compatible long-term management routes (notably gas production during the disposal's operation phase) for organic waste contaminated with alpha-emitting radionuclides will be an orientation of important work. This aspect is especially developed in section 3.3. of this report.

In the near future, other types of presently stored historical waste could undergo processing for its recovery and prior to its conditioning. This is the case, for example, of UNGG fuel cladding waste stored at La Hague.

To optimise a process, it is also necessary to follow a safety approach so that the disposal performs its confinement function until the radioactivity of the radionuclides contained in the waste has sufficiently dropped. The radiological impact induced by the retained management route must also be as small as possible.

Improving the characterisation of waste to guarantee quality and traceability

A better knowledge about the radiological and physico-chemical contents of the waste package will allow better defining the conditioning and the management route. A more accurate determination of the natures and quantities of radioelements is an ongoing objective and the advances made in this field are paced with the technical progress accomplished in the technology of sensors and discrimination techniques. They should lead to more rapid analyses and be less generators of secondary waste.

Minimising discharged effluents, particularly by the permanent evolution of authorisations

The boundary between the discharge of effluents and the production of waste is the result of an optimisation process specific to each facility. Generally there is a point below which the concentration in radioelements or other toxic substances in the effluents is no longer likely be recovered. This operating point, which is determined on a case by case basis by an optimisation process, can lead to debates, technological choices, and generally downturns as the techniques gradually develop. The optimisation process is restrained by regulatory texts. Moreover, prescriptions limit discharges strictly to a number of top priority pollutants and regulate in detail the processing, treatment and control for effluents originating from nuclear activities or industrial activities. An impact study is systematically required for any activity leading to discharges in the environment. This impact study must guarantee that the impact of the discharges on the environment remains negligible. In all cases, and particularly when the handled pollutant concentrations are high, it may be said that the radioactivity released in the effluents represents a very small part of that which is fixed in the waste and, as a result, it is a very marginal fraction of the radioactivity at stake. However, in some cases, the management of the elimination of radioactive substances may be studied by the pathway of discharges ; these discharges concern only very low quantities of radioactivity in polluted site situations, as well as radioelements which cannot be technically retained for the processing of the effluents, such as tritium and carbon 14 in a gaseous state, when handled activities are minimum. Still, operators are requested to think about the techniques to be implemented to reduce as much as possible the discharges linked to these activities. In fact, management by discharge must be minimised, on the one hand, due to accumulation phenomena and, on the other hand, due to the lack of data on the impact resulting from low chronic doses - both chemical and radioactive.

Optimising the dosimetry of personnel and populations

The mainline principles for protection against ionising radiation have been defined by the International Radiological Protection Commission (IRPC) and concern :

- the justification of the activities (technical, economic and ethical)
- the optimisation of the consequences (doses)
- the limitation of the consequences (doses)

The effectiveness of the optimisation approach (optimise the radiological protection level) rests on the general dissemination of the radiological risk culture. All these principles are evidently also applicable to the field of radioactive waste management.

1.3. The legal and institutional framework of waste management in France

In consistency with the aforementioned principles, France is endowed with a legal and institutional framework for the managment of radioactive materials and waste, notably the Act of 28 June 2006 related to the sustainable management of radioactive materials and waste.

1.3.1. The legislative and regulatory framework

Background and context of the elaboration of the Act of 28 June 2006

Major actions were taken a long time ago to ensure an adapted and sustainable management of radioactive waste : 85% of the volume of produced waste is taken care of today in surface disposal centres managed by Andra. These centres are located in the Manche and Aube departments ; the Manche site has been covered over and has entered the monitoring phase, while the Aube sites are still in operation.

The remaining 15%, which concentrate 99% of the radioactivity, are stored in surface facilities, notably La Hague (Manche), Marcoule (Gard) and Cadarache (Bouches-du-Rhône). These facilities have been designed to dispose of waste transitorily pending an ultimate outlet.

To define long-term management routes, France has engaged in ambitious research and study programmes like other countries also concerned, such as the United States, Finland, Switzerland and even Germany. In particular, the French Parliament voted on 30 December 1991 a specific Act fixing three orientations of research and stipulating that the Government would present a new draft law by 30 December 2006 based on the results of the research conducted in each of these orientations :

1. Orientation 1, aimed at reducing the volume and the toxicity of the waste by separating the various products contained in the spent fuels (the so-called "separation" process) and by transforming the long lived radioactive elements into shorter lived radioactive elements in new nuclear reactors (the so-called "transmutation" process). This option assumed the development of a new generation of reprocessing plants and a new generation of nuclear reactors.
2. Orientation 2, was the irreversible or reversible disposal of waste in a deep geological layer. Radioactive waste repositories already exist, but they are located on the surface and are dedicated to short lived waste. Disposal possibilities in a deep geological layer for long lived radioactive waste were studied, notably thanks to the Andra laboratory at Bure on the borders of the Meuse and Haute-Marne departments in an old, deep and stable geological layer of approximately 150 million years.
3. Orientation 3, concerned the study of long-term waste conditioning and storage processes. It aimed at the development of facilities which would allow storing the waste safely on the surface for 100 to 300 years, versus 50 to 100 years for currently operated storages. Since a storage is by definition temporary, the waste would be finally removed.

This research conducted under the auspices of the Atomic Energy Commission (CEA) (for orientations 1 and 3) and Andra (for orientation 2) resulted in many scientific collaborations nationally (with the CNRS and universities) and internationally. They were finalised during the year 2005 and resulted in summary reports submitted to the ministries of the industry and research.

Several evaluation and consultation initiatives were launched in 2005 and 2006 based on this research, namely :

- the report published in March 2005 by the Parliamentary Office for Evaluation of Scientific and Technological Options (OPECST) under the auspices of the Deputies Christian Bataille and Claude Birraux and titled "For a sustainable management of radioactive materials and waste" ;
- the evaluations of the research results made by the National Evaluation Committee (CNE) composed of independent experts, the Nuclear Safety Authority (ASN), and by the panels of foreign experts selected by the Organisation for Economic Co-Operation and Development (OECD)'s Nuclear Energy Agency (NEA) ;
- the public debate conducted from September 2005 to January 2006 by the National Public Debate Committee (CNDP) during which the Committee for the first time did not debate a concrete infrastructure project, but debated an issue of general policy in the domain of the environment.

These various elements completed by the opinions submitted by the Council of State and the Council of Economic and Social Matters allowed the Government to elaborate a draft law in 2006 concerning the management of radioactive materials and waste. The public debate and parliamentary examination led to major evolutions concerning notably the accounting for radioactive materials (and not simply waste), the objectives for the new research phase, the Parliament's role after 2006, the concept of reversibility, local consultation modalities, the sponsoring system for the concerned regions, and the securing of the financial resources necessary for the management of the radioactive waste and the dismantling of nuclear facilities. The Act no. 2006-739 of 28 June 2006 related to the sustainable management of radioactive materials and waste was finally published in the Journal Officiel of 29 June 2006.

Act of 28 June 2006 related to the sustainable management of radioactive materials and waste

Under the terms of the Act of 28 June 2006, the sustainable management of radioactive materials and waste must comply with the following principles : protection of human health, safety and the environment ; prevention or limitation of undue burdens to be supported by future generations ; principle of pollutant-payer.
The Act treats three main topics : (i) definition of a management policy for radioactive materials and waste, (ii) improvement of the transparency and democratic control, (iii) funding and sponsoring provisions.

First, for the *management policy*, the Act fixes the management orientations for all the radioactive materials and waste in article 6 :

- reduction of the quantity and harmfulness of the waste, notably reduction at the source by spent fuels reprocessing, and, in the future, if necessary, by extensive separation / transmutation ;
- storage as a preliminary phase, notably with the perspective of reprocessing fuels and waste, or the disposal of the waste ;
- after storage, disposal in a deep geological layer as a perennial solution for ultimate waste which cannot be disposed of on the surface or at a low depth disposal.

In addition, article 6 of the Act provides for the elaboration every three years of this document, the National Plan for the Management of Radioactive Materials and Waste (PNGMDR). This Plan described in more detail in section 1.3.2 aims at :

- establishing the status of the existing management methods for radioactive materials and waste ;
- reporting on the estimated needs for storage or disposal facilities and specifying the necessary capacities, as well as the storage durations ;
- determining the objectives to be attained for radioactive waste for which there is still no final management method ; the plan organises, in particular, the research and studies to be conducted on the management of radioactive waste and fixes the timetables for the implementation of new management methods and the creation or modification of facilities.

The Act also defines a research programme for the management of all radioactive materials and waste (articles 3 and 4). For high or intermediate level and long lived waste, three orientations are prescribed in consistency with those of the Act of 1991.

1. For orientation 1, related to the separation and the transmutation of long lived radioactive elements, an assessment will be drawn up in 2012 between the various transmutation processes. Depending on the results which will be obtained within the framework of this assessment, facility prototypes could be constructed beginning in 2020 and an industrial deployment envisioned around 2040.
2. For orientation 2, related to the disposal possibilities of waste in a deep geological layer, the Act of 2006 confirms the orientations taken in 1991 and now imposes that the concept developed by Andra be reversible. For the milestones fixed by the Act, it is requested that the disposal authorisation procedure be enacted in 2015 and that it be applicable in 2025, provided the preliminary enactment is favourable.
3. Orientation 3, extensively reviewed by the Act of 2006, abandons, in particular, the concept of the "long storage duration". The Act stipulates that hereafter the research and studies will be conducted by Andra in order to create new storage facilities or modify existing facilities at the latest by 2015.

The prohibition to store in France radioactive waste originating from a foreign country legalised by the Act of 1991 is reasserted and prescribed in article 8 of the Act of 28 June 2006. In particular, the entry of spent fuels or radioactive waste in France is allowed only for reprocessing, research or transfer between foreign States. Moreover, the entry for reprocessing must be covered by an intergovernmental agreement which should notably specify a date after which the waste originating from the processed substances cannot be stored in France.

For "orphan" waste, article 14 of the Act of 28 June 2006 entrusts to Andra the mission of collecting, transporting and taking care of the radioactive waste and cleaning up the radioactive pollution sites upon request and at the expense of their owners or on public requisition when the people responsible for this waste or these sites default.

In the field of *transparency and democratic control*, the National Evaluation Commission (CNE), created by the Act of 1991, is responsible for annually evaluating the advancement of the research and studies related to the management of radioactive materials and waste. The Act of 2006 notably reviewed the operating modalities and membership.

Moreover, a Local Committee on Information and Follow-up (CLIS) is included in the Meuse / Haute-Marne underground research laboratory. Following the Act of 2006, its operation was modified, its membership broadened and its presidency entrusted to a national or local elected official.

The Act also specifies new milestones to authorise the creation and closing phases of the future deep geological repository. Thus, a first Act must fix the reversibility conditions after public debate and consultation with the concerned territorial communities before a decree can authorise the creation of the disposal centre around 2015. In the longer term, only an Act may authorise the final closing of the repository.

The High Committee for Transparency and Information on Nuclear Safety (HCTISN), created by the Act of 13 June 2006 related to the transparency and safety in nuclear matters, is also responsible for periodically organising consultations and debates concerning the sustainable management of radioactive materials and waste.

Finally, the Act provides for *funding provisions,* as well as *the modernisation of the local sponsorship system* (articles 13 and 21) of the underground research laboratory and the future deep geological repository.

The funding modalities of the three research orientations are prescribed by the Act (articles 15, 16 and 17) ; in particular, the research conducted by Andra on orientations 2 and 3 are funded by an additional tax allocated to the basic nuclear facilities tax.

To secure the funding for the long-term nuclear obligations (article 20), the Act stipulates that each industrialist make provisions and assign assets dedicated to the coverage of these obligations before mid-2011. These costs include the management costs for spent fuels and radioactive waste, as well as the costs for dismantling basic nuclear facilities (or, for radioactive waste disposal facilities, final shutdown, maintenance and monitoring costs). A system enclosing the practices of the operators in this field is created with, in particular, the implementation of a direct control on the part of the State on the evaluation and cost coverage modalities. Thus, three-year reports are provided for, as well as annual updates, which are appraised by the control authority. In addition, the Act creates a National Evaluation and Funding Committee (CNEF) for long-term nuclear costs to evaluate the controls implemented by the State.

Finally, to accompany the territories located in the proximity of an underground research laboratory or a deep geological repository, the Public Interest Groups (pre-existent in the Meuse and Haute-Marne) now have three missions : (i) manage the equipment suitable for the installation of an underground research laboratory or a repository ; (ii) implement within the department's limits territorial and economic development actions, particularly in a "zone of proximity" around the facility ; (iii) support training actions, as well as actions to promote the development, valorisation and dissemination of scientific and technological knowledge, notably in the fields studied in the laboratory and in those of new energy technologies. These missions will be funded by additional taxes allocated to the already existing tax for basic nuclear facilities.

Implementing the Act of 28 June 2006

All the decrees to be promulgated since the publication of the Act of 28 June 2006 have been published as indicated in the table below.

	Purpose of the decree	Act's article	Signing date
National policy for the management of radioactive materials and waste	Definition of a national plan for the management of radioactive materials and waste	Art. 6	16 April 2008
	Management of foreign waste and processing contracts	Art. 8	3 March 2008
	Nomination of CNE members	Art. 9	5 April 2007
	Kind of information to be transmitted for the national inventory and the PNGMDR	Art. 22	29 August 2008
Sponsoring of the research conducted in the Meuse / Haute-Marne underground research laboratory	CLIS	Art. 18	7 May 2007
	Public interest groupes (PIGs) – Generic decree	Art. 13	14 December 2006
	Definition of the zone of proximity - Meuse and Haute-Marne PIGs	Art. 13	5 February 2007
	"Sponsoring" tax : fraction paid by the PIGs to the communities of the zone within 10 km	Art. 21	7 May 2007
	Coefficient of the "sponsoring" and "technological dissemination" taxes	Art. 21	26 December 2007
	Consultation zone for the creation of a disposal	Art. 12	To be published in 2012
Funding provisions	Additional "research" tax coefficient	Art. 21	26 December 2007
	Securing of long-term nuclear costs	Art. 20	23 February 2007
	Set up of the National Review Board funding (CNEF)	Art. 20	20 June 2008

In particular, the management policy was prescribed by the decree of 16 April 2008 stipulating the prescriptions related to the National Plan for the Management of Radioactive Materials and Waste. Its article 3 indicates that the producers and holders of radioactive waste are responsible for ensuring or having ensured the management of the waste according to the orientations stated in article L.542-1-2 of the Environmental code. To this end :

1. The radioactive waste management system must be made consistent, as well as its technical and economic optimisation ;
2. The radioactive waste disposal centres, which are limited in number and capacities, must be used in the best possible fashion by the various players ;
3. The radioactive waste management routes take into account the volumes of transported waste and the distances travelled between the storage sites and the disposal sites.

Let us recall here the principle of the responsibility of a waste holder, who must pay the costs to have it taken care of in an authorised process.

Other texts

The management of radioactive materials and waste is also governed by other acts and laws and international agreements.

The Act of 13 July 2005 fixing the orientations of the energy policy thus defines several priorities, including the maintaining of the nuclear option opened around 2020. It also stipulates that research has to be developed in the energy sector, notably for future nuclear reactor technologies (fission or fusion), particularly with the support of the ITER programme, and also the technologies required for a sustainable management of radioactive waste.

Moreover, the Act of 13 June 2006 related to the transparency and safety in nuclear matters (the so-called TSN act) applies to the management of radioactive materials and waste, notably some provisions related to basic nuclear facilities (category covering most of the radioactive waste disposal centres) or to the transport of radioactive substances.

The management of radioactive waste originating from basic nuclear facilities is based on a strict regulatory framework prescribed by a ministerial order of 31 December 1999 fixing the general technical regulations intended to prevent and limit nuisances and external risks resulting from the operation of the basic nuclear facilities. This ministerial order recalls the necessity for the operator to take all the necessary provisions in the design and operation of his facilities to ensure an optimal management of the produced waste, notably taking into account subsequent management routes. As required by this order, a study shall be written to specify the management modalities for waste produced in the basic nuclear facilities. One of the sections of this study must be submitted to ASN for approval. Within the renovation framework of the regulatory structure of the basic nuclear facilities (INBs) resulting from the "TSN" Act, this ministerial order will be shortly revised and the prescriptions related to the management of the waste in the IBNs will be combined in a new ministerial order. An ASN decision will complete the provisions related to the management modalities for waste produced in the basic nuclear facilities.

The management of radioactive waste originating from secret basic nuclear facilities (INBSs) is prescribed in a ministerial order of 26 September 2007 fixing the general technical regulations intended to prevent and limit nuisances and external risks resulting from the operation of secret basic nuclear facilities. Title VI of this ministerial order recalls the necessity for the operator to take all necessary provisions to reduce the volume, the radiological, chemical and biological toxicity of the waste produced in its facilities and to optimise its management by making sure to favour its recovery and its processing for a final disposal reserved for ultimate waste. A summary document shall be written to specify the management modalities for waste produced in secret basic nuclear facilities. This document must be submitted for approval to the Nuclear Defence Safety Delegate (DSND) and serves as a referential for the optimised management of waste produced in INBSs.

In the case of radioactive waste produced outside of basic nuclear facilities and secret basic nuclear facilities, article R. 1333-12 of the Public Health Code stipulates that the management of effluents and waste contaminated by radioactive substances originating from all nuclear activities intended for medicine, human biology or biomedical research involving a risk of exposure to ionising radiation must be investigated and approved by public authorities. The Nuclear Safety Authority's decision on 29 January 2008, which was certified by the ministers of health and the environment, placing in application the provisions of article R. 1333-12 of the Public Health Code, fixes the technical rules which must be followed to eliminate the effluents and the waste contaminated by radionuclides or liable to be contaminated due to a nuclear activity.

At the international level, the issue of radioactive waste is treated particularly through radiological protection and safety referentials (elaborated notably by the International Atomic Energy Agency (IAEA)) and at the level of various working groups, notably within the OECD's NEA, or the working groups of the European Nuclear Energy Forum (ENEF) and the European Nuclear Safety Regulators Group (ENSREG). Moreover, an international incitement convention (Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management) to which 51 States participate promotes principles on the matter and organises peer reviews every three years. Bilateral agreements can also be signed, in conformity with article 8 of the Act of 28 June 2006, to regulate the importation for reprocessing spent fuels or radioactive waste in order to enforce the prohibition of disposal in France of radioactive waste originating from outside of France.

1.3.2. The National Plan for the Management of Radioactive Materials and Waste (PNGMDR)

As indicated in section 1.3.1, article 6 of the Act of 28 June 2006 defines the objectives of the National Plan for the Management of Radioactive Materials and Waste (PNGMDR) :

- Assess the existing management methods for radioactive materials and waste ;
- Report on the estimated needs of storage or disposal facilities and specify the necessary capacities, as well as the storage durations ;
- Determine the objectives to be attained for radioactive waste for which there is still no final management method. The plan organises, in particular, the research and studies to be conducted on the management of radioactive waste and fixes the timetables for the implementation of new management methods and the creation or modification of facilities.

The Act stipulates that the PNGMDR is to be published every three years and that a decree fixes in terms of regulations the prescriptions resulting from it. The Plan must include in the annex a summary of the achievements and the research conducted in foreign countries. It is communicated to Parliament, which in turn submits it to the Parliamentary Office for Evaluation of Scientific and Technological Options (OPECST) for evaluation, and is rendered public.

The first version of the PNGMDR was communicated to Parliament in 2007 based on the work of a multi-party working group. It was prepared to a great extent in concomitancy with the Act of 28 June 2006. Then adjustments and updates had to be made to take into account the Act's prescriptions. A summary of this plan was subsequently published.

To update the PNGMDR, the Government decided to continue to rely on the work of a multi-party working group. The working group is presided jointly by DGEC and ASN ; the ASN membership consists of notably waste producers and managers, associations, elected official representatives, administrations, CNE, DSND and IRSN. Many presentations made within the working group constituted a very precious source of information for the elaboration of the plan.

This update is also based on the national inventory of reusable materials and radioactive waste published by Andra in mid-2009 for the waste production perspectives in the coming decades and for storage needs and capacities. Due to the large number of waste families identified in the national inventory (one hundred), the PNGMDR combines family groups in order to present a summary vision of the management routes.

The new edition relies, in addition, on the results of all the engaged studies, in conformity with the decree of 16 April 2008 fixing the prescriptions related to the PNGMDR.

In the ongoing elaboration of the previous PNGMDR, the engaged approach for the revision of the PNGMDR thus relies heavily on multi-party participation and transparency, in consistency with the "Grenelle Environment Round Table on Public Policy for Ecological and Sustainable Development Issues".

Finally, the utility of a National Plan for the Management of Radioactive Materials and Waste was confirmed at the European level. The European Nuclear Safety Regulators Group (ENSREG), created in 2007, underlined the necessity of developing national management programmes. The European Council also confirmed this concern : the resolution of 16 December 2008 on the management of spent fuel and radioactive waste indicates that "the implementation by each Member State of a national plan for the management of spent fuel and radioactive waste is mandatory. Such plans must take place over the long term, cover all types of radioactive waste, and describe all the stages of its implementation. They must at least include an inventory of the spent fuel and radioactive waste present in the country and the future perspectives, examine the existing solutions, define the R&D strategies deployed to improve the existing solutions or develop new solutions, establish a timetable for the implementation of these solutions, evaluate their costs and their funding methods, describe the regulatory framework and the decision-making processes for the implementation of new solutions, and finally determine the spheres of responsibility. Such a plan must be made accessible to the public, reviewed and, if necessary, regularly revised."

1.3.3. The players in the management of radioactive materials and waste

The producers of radioactive materials and waste can be grouped into five economic sectors (cf. 1.1.2): electronuclear, defence, research, non-electronuclear industry, medical. From a global inventory viewpoint, three main waste producers can be mentioned as indicated in the national inventory of reusable materials and radioactive waste 2009 : they are in alphabetical order AREVA, CEA and EDF.

The manager of radioactive waste in France is a specialised public institution called Andra (National Agency for Radioactive Waste Management). Andra's missions detailed in the Act of 28 June 2006 consist of notably the design and operation of disposal centres, the performance of research and studies on storage and disposal in a deep geological layer, the collection of radioactive waste for owners who default, and the dissemination of information to the public.

The main French research institutes in the field of the management of radioactive materials and waste are, in addition to Andra, already mentioned, BRGM (Office of Geological and Mining Research), CNRS (which has structured its research around an interdisciplinary research programme), PACEN (Programme on the Downstream of the Cycle and Nuclear Energy), INERIS (National Institute of the Industrial Environment and Risks), IRSN, the Institut Carnot MINES (Carnot Institute's "Innovative Methods for the Enterprise and the Society"), as well as universities. The Act of 28 June 2006, in particular, conferred the responsibility of the separation-transmutation research to CEA, and the research on storage and disposal to Andra. IRSN research is aimed at reaching a sufficient level of expertise to be able to play its role as a technical support to the safety authorities (ASN and DSND). In parallel, a number of R&D actions are performed by the industrialists (EDF and AREVA) partly associated with CEA and/or Andra by general agreements. The purpose of a Committee for Research Orientation and Follow-Up Downstream from the Cycle (COSRAC) is to ensure the consistency of these research programmes. Finally, the National Evaluation Commission, whose role was confirmed by the Act of 28 June 2006, ensures an annual evaluation of the research in the field of the management of radioactive materials and waste.

Several ministries participate in the definition, implementation and control of the policy for the management of radioactive materials and waste. Within the Ministry of Ecology, Energy, Sustainable Development and Sea (MEEDDM), the General Directorate for Energy and Climate (DGEC) elaborates the policy and implements the Government's decisions related to the civil nuclear sector, except for those dealing with nuclear safety and radiological protection. Also within the MEEDDM, the General Directorate for Risk Prevention (DGPR) elaborates, coordinates and implements the Government's missions concerning civil nuclear safety and radiological protection, except for missions entrusted to ASN (see hereafter). Within the Ministry of Higher Education and Research (MESR), the General Directorate of Research and Innovation (DGRI) coordinates the French research efforts.

There are two authorities in France to control nuclear safety and radiological protection : The Nuclear Safety Authority (ASN) fulfils the task of controlling nuclear safety and radiological protection for civil nuclear facilities and activities. It is an independent administrative authority, created by the Act of 13 June 2006 related to transparency and safety in nuclear matters. The nuclear safety authority for activities and facilities of interest to defence is the delegate for the nuclear safety and radiological protection of facilities and activities interesting defence (DSND). The DSND is placed under the Defence Minister and the Industry Minister. IRSN intervenes to provide technical support to nuclear safety authorities.

Within Parliament, the Parliamentary Office for Evaluation of Scientific and Technological Options (OPECST) can make evaluations in order to inform it about the consequences of scientific and technological options. These evaluations can notably concern the nuclear energy field. The Parliament's role and its long-term engagement must be focused on the follow-up and the elaboration of the national policy for the management of radioactive materials and waste.

Within the framework of exchanges organised to promote transparency and consultation, many other players are invited to participate in the definition of the management policy for radioactive materials and waste. Thus, representatives of the civil society and environment protection associations participate in the PNGMDR working group, such as ACRO (Association for the Control of Radioactivity of the West), Robin des Bois, GSIEN (Group of Scientists for Information on Nuclear Energy) and WISE - Paris (World Information Service on Energy). Representatives of elected officials, such as the Association of French Mayors, also actively take part in this work. The Act of 28 June 2006 stipulates, in addition, that a High Committee for Transparency and Information on Nuclear Safety (HCTISN) periodically organise debates and consultations on this theme. Exchanges also take place within the Local Committee on Information and Follow-up (CLIS) installed in the Meuse / Haute-Marne underground research laboratory, as well as within Local Information Committees (CLI) located around the Basic Nuclear Facilities (INBs) and united in a National Association of CLIs (ANCLI).

Finally, international organisations work on the harmonisation of the management policies between the various countries : The EURATOM (European Atomic Energy Community) at the European level, the NEA (Nuclear Energy Agency) within the OECD (Organisation for Economic Co-Operation and Development) and the IAEA (International Atomic Energy Agency) reporting to the United Nations General Assembly.

2. Assessment of the existing management routes and those under development at the end of 2009

The existing management routes and those under development at the end of 2009 consist of :

- storage of radioactive materials and waste awaiting disposal, including the management method by decay for very short lived waste ;
- reuse of some radioactive materials, such as spent fuels, uranium, or plutonium ;
- long-term management of waste by means of disposal centres dedicated to radioactive waste ;
- other existing management methods for the management of radioactive waste, notably in-situ disposal or disposal in conventional disposal centres ;
- management routes under development for waste containing tritium, sealed radioactive sources, low level and long lived (LL-LL) waste, and high or intermediate level and long lived (HL/IL-LL) waste.

2.1. Storage of radioactive materials and waste awaiting disposal

The storage of radioactive waste is an operation which consists in temporarily placing it in a facility arranged for this purpose in order to allow a waiting, a grouping, a monitoring or an observation. Unlike a disposal centre, radioactive waste storage sites are not designed to fulfil safety functions over the long term, but rather only for a given duration (in particular, they necessitate maintenance and human interventions to monitor the packages). However, they may exist on each disposal site to perform the controls and especially allow the packages to wait (cooling of glasses, for example) before they are disposed of. At the end of the storage period (depending on the opening of a disposal site), the waste is necessarily removed from the facility. This facility will be reused or dismantled at the appropriate time. Moreover, storage facilities offer safety guarantees which are proportional to the types of waste they accommodate. There are three types of radioactive waste storages :

- short-term storages, linked to radioactive waste management by radioactive decay ;
- old storages, which no longer perfectly comply with current safety standards and must be emptied in the more or less near future ;
- more recent storages, which comply with safety standards and for which it is necessary to verify the adequacy with waste production forecasts.

2.1.1. Storage and management of radioactive waste by radioactive decay

The management of radioactive waste by radioactive decay on the site where it is produced is reserved for waste containing radioelements with a half-life less than 100 days. The objective is to wait until the waste's activity has sufficiently decreased so that it can be eliminated by a conventional management route. The main concerned establishments are nuclear medicine services and research laboratories.

The evolution of the regulations which took place in 2008 confirms this approach. The Nuclear Safety Authority's decision no. 2008-DC-0095 of 29 January 2008, certified by the ministerial order of 23 July 2008 and placed in application by article R.1333-12 of the Public Health Code, fixes the technical rules which must be complied with for the elimination of effluents and waste contaminated by radionuclides or liable to be contaminated. Waste can only be directed to a non-radioactive waste management solution after a delay greater than ten times the half-life of the radionuclide (in case several radionuclides are present, the longest half-life will be retained). This ministerial order provides for notably the implementation of a management plan for contaminated effluents and waste, including the management modalities inside the concerned establishment, the identification of the sites where the contaminated waste is to be stored and the provisions to ensure its elimination in adapted management routes, as well as the associated control modalities.

2.1.2. Old radioactive waste storages

This section concentrates on radioactive waste storage sites which no longer completely satisfy current safety requirements ; operations either to recover the waste, or to improve or reinforce storage facilities must be programmed. These old storage sites concern facilities classified as basic nuclear facilities (INB), facilities classified for the protection of the environment (ICPE) and finally secret basic nuclear facilities (INBSs).

Radioactive waste storages classified "basic nuclear facilities" (INB)

Old radioactive waste storage sites classified INB include the AREVA Company's facilities at La Hague and the CEA research centres (Cadarache, Saclay, Grenoble and Fontenay), as well as EDF owned facilities. The waste stored in these facilities is intended to undergo recovery operations. However, these operations can sometimes be difficult to carry out and are not always conducted with the priority they should be given by the concerned operators ; this leads to frequent delays with respect to the announced timetables.

The main challenge in the coming years is to make sure that commitments are respected, notably in terms of deadlines, and that pending a complete destorage the safety level of the facilities remains acceptable. The ASN report[8] submitted on 23 September to the High Commission for Transparency and Information on Nuclear Safety (HCTISN) related to old radioactive waste storage sites draws up a complete inventory of old radioactive waste storage sites. The main items of the report are referred to hereafter.

The old AREVA storage sites at La Hague

Contrary to what was done for the new plants of UP2 800 and UP3 A, the old plants of La Hague (UP2 400 and STE2) had not been thought to accommodate inline conditioning of their waste. Most of this waste has, therefore, been stored without any final conditioning pending its recovery and reprocessing in a nuclear management route.

Sludge of the STE2 effluent reprocessing plant
From 1966 to 1997, effluents from La Hague were processed in the STE2 facility by chemical co-precipitation. After this process, 9300 m^3 of sludge remain stored in the silos.

The HAO and SOC silos
The HAO (880 t of waste) and SOC (1220 t) silos contain various waste consisting of hulls and end-caps, fines (dust originating essentially from shearing), resins and technological waste originating from the HAO workshop (UP2 400) between 1976 and 1997.
The main safety issues linked to the storage of this waste are the lack of possible control of the leak-tightness of the lining, the pyrophoricity of some waste (risk of fire in case of unwatering) and possibly the criticality.

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8 See also the HCTSIN recommendation of 7 November 2008 on the radio-ecological monitoring of the water around the nuclear facilities and on the management of old radioactive waste storage sites at the following address : www.hctisn.fr

The 130 silo :
The 130 silo contains waste originating from the reprocessing fuels from the UNGG management route. The stored waste mass is 650 t, including approximately 480 t of graphite.

Alpha waste of building 119
A global strategy was implemented by the operator to process in priority the existing alpha waste drums which are currently stored in building 119, whose safety was not judged completely satisfactory with respect to the risks of earthquake and fire.

Old EDF storage sites

Most of the old waste stored by EDF is graphite waste, whose recovery is conditioned by the availability of an outlet, a disposal after storage being possible for this waste.

The silos of Saint-Laurent
The storage silos of Saint-Laurent (INB no. 74) contain mainly irradiated graphite sleeves with or without saddle wire. Considering the delay in executing the recovery operations of the waste stored in these silos pending the creation of a low level and long lived waste disposal management route and the problem of demonstrating the leak-tightness of these silos over time (the safety level of the silos does not satisfy current criteria concerning the behaviour of the civil engineering structure under the effect of an earthquake.), EDF intends to install a geotechnical enclosure around this facility. This enclosure completed by an "interior" groundwater pumping system would prevent any contact between the water table and the floating foundation of the silos.

The mounds of Bugey
During soil studies for the installation of the ICEDA storage facility on the Bugey site in 2006, EDF wondered whether waste might be present in two mounds composed mainly of backfill located to the south of the nuclear power plant. An internal enquiry was conducted to reconstitute the history of the mounds, which result from earthwork performed on the site in 1965. They contain not only old worksite residues from the pressurised water reactors, but also resins of a very low radioactivity level which were used to purify the reactor's cooling circuits. The historical record shows that these resins, which were produced beginning in 1979, were first stored pending decay before they were discharged, after confirmation that they had sufficiently decayed, in the zone of the mounds in 1983. However, analyses showed that these mounds were not at the origin of the contamination of the water table located directly underneath the site. As of 1983, the resins were stored before being eliminated by a nuclear management route.

The old CEA storage sites

<u>The Centre of Cadarache</u>

- *INB 22 - PEGASE*

PEGASE is an old experimental reactor decommissioned in 1980. This facility is now used for the storage of fuel elements under water in the pool and the basins of the reactor's leak-tight enclosure, as well as for the storage of more than 2700 drums of plutonium-bearing by-products. Considering the extent of the work required for the reinforcement of the facility against earthquake to allow the PEGASE reactor to continue to operate, CEA proposed in December 2004 a decommissioning of the facility and an evacuation of the drums and the spent fuels. The operator, however, performed work to enhance the safety of the facility, notably against the risk of fire and the dynamic confinement of the storage premises of the plutonium-bearing drums.

- *INB 56 - The installed storage base of Cadarache*

The installed radioactive waste storage base (INB no. 56) located at Cadarache is a facility which went into operation in 1963 and whose mission was to store solid radioactive waste originating from the operation or the dismantling of CEA facilities. The waste is stored here in concrete pits for the most irradiating or in hangars. Irradiated fuel elements were also stored in the pool, but were evacuated in 2004. A part of the installed storage base also includes 5 trenches, which were filled between 1969 and 1974 with various low or intermediate level solid waste and then covered with earth. Within the site's clean up and rehabilitation framework, the recovery of all the waste was requested. For the trenches, the recovery began in 2005, but the recovery operations for some waste have repeatedly been deferred. The FOSSEA project provides for the recovery and reconditioning of all the packages stored in the pits for the purpose of storing them at CEDRA after a possible complementary characterisation and reconditioning. CEA agreed to begin the destoring of the so-called F3 pit and recover first the pits F5 and F6. The recovery of the other pits should take place later on. The waste packages stored in the hangars are either being evacuated to CEDRA or awaiting shipment to CSA.

The Centre of Saclay

- *INB 35 - STEL*

The radioactive liquid effluents management zone (ZGEL), also denoted STEL, is used to collect, store and process low level aqueous effluents, and store old organic and aqueous concentrates. The STELLA facility must be shortly placed in operation to replace the old evaporator and the bituminising process for the concentrates by a cementation process in order to resume the processing of the centre's effluents. As for the storage of old concentrates present on INB 35, the emptying of tanks MA 501 to MA 507 and the first transfers of the organic phase of tank MA 508 are being examined by CEA, and they must be evacuated before the end of 2013.

- *INB 72 - STDS*

The solid waste management zone is used to process, characterise and store the solid radioactive residues produced by the reactors, laboratories and workshops of the Saclay Centre. It also recovers waste originating from small producers (sources, scintillating liquids, ion exchange resins) and stores unused radioactive sources. CEA has scheduled the operational decommissioning of this facility by 2017. The CEA current strategy aims at reducing the "source" term present in the facility by recovering the old storages of spent fuels in pools, in massifs and in shafts.

The Centre of Grenoble

In 2000, it was decided to denuclearize the CEA centre of Grenoble, which had been inaugurated in 1959, because of its close proximity to greater Grenoble, reduced research and development needs, and the ageing of the facilities. The six basic nuclear facilities of the site have gradually passed into the end of operation and then dismantling phase before being decommissioned. The total decommissioning of the site is scheduled for around 2015. Among the Centre's 6 INBs, INB79 is a storage by decay of intermediate level waste containers. This storage located in a pit has 63 vertical shafts. Since 2005, no primary producer waste has been stored here ; the only waste authorised to be accommodated in the shafts is the waste originating from the sorting or reconditioning of waste from INB 79.

The Centre of Fontenay

In 1999, CEA initiated the "denuclearization" of the Centre of Fontenay-aux-Roses, which is the first French nuclear research centre because of its close proximity to Paris and the old age of its research facilities. A clean-up programme for the site and both INBs on it was elaborated. Among these facilities, the Fontenay aux Roses site includes a storage for high or intermediate irradiating radioactive waste generated by the site's activities. This storage consists of 128 shafts accommodating 1536 x 50 litre drums, 40 shafts accommodating 243 drums of 200 or 220 litres, and 10 cells (global volume of 132 m^3) designed to accommodate various waste canisters. The waste must be evacuated under the dismantling project of the site's INBs.

Radioactive waste storages classified "secret basic nuclear facilities" (INBS)

Some basic nuclear facilities classified secret (INBS) store "historical" radioactive waste ; all this waste is to be eventually evacuated to the ANDRA disposal centres. These storages are listed in the national inventory established by ANDRA.
DSND monitors the programmes to clean up the facilities and transfer the stored waste to final disposals. The DSND report[9] submitted on 23 September to the High Commission for Transparency and Information on Nuclear Safety (HCTISN) related to old radioactive waste storage sites draws up a complete inventory of the old radioactive waste storage sites on the INBSs. The main items of the report are referred to hereafter.

For the INBS of Marcoule, spent fuel reprocessing activities were shut down in 1997. The facilities are being cleaned up and dismantled, and old waste conditioning and reconditioning operations are in progress. There are several storage facilities at Marcoule and the main ones are :

- The 5 pits of the AVM workshop for vitrified waste ;
- The 14 casemates of the STEL workshop for effluent processing waste : bituminised sludge in 230-litre drums ;
- The pits and the buildings of the North zone ;
- The EIP, a recent storage for bituminised sludge drums over-packed in 380-litre drums within the framework of the programme to recover the pits in the North zone and the casemates of the STEL ;
- The MAR400 and uncladding pits for the fuel cladding waste and for the process waste ;

For the INBS of Pierrelatte, the waste resulting from production and dismantling activities are evacuated to existing management routes (Very Low Level Lisposal Centre, CSA and CENTRACO) and are not sustainably stored on the site. There are two old waste storages : the "mound" and the pits of the North zone. The "mound" contains gaseous diffusion barriers, technological waste, fluorines and inactive sludge rich in chromium. The twelve waste pits of the North zone contain building deconstruction rubbish slightly contaminated from the clean up of premises accommodating CEA research activities. The recovery modalities for the waste from the mound and the pits are prescribed in section 3.1.1.

For the INBS of Valduc, the produced and stored waste is subdivided into two main categories : alpha-emitting waste and tritium-bearing waste. The alpha waste stock is undergoing resorption and waste not compatible with the specifications of the existing disposal processes is evacuated to the Cadarache site for storage pending the opening of the new ANDRA disposals. For the waste containing tritium, the lack of an operational elimination management route is leading to a continuous growth of stored stocks (cf. section 2.5.1).

For the INBS of Valduc, the produced and stored waste is subdivided into two main categories : on the one hand, low or intermediate level tritium-bearing waste intended for a surface disposal centre and even for a recycling management route, and, on the other hand, alpha-emitting waste. The IL-LL alpha waste is evacuated to the Cadarache site for storage pending the opening of the new Andra disposals. In the absence of an outlet, the tritium-bearing waste is stripped of its tritium in a facility specific for the most active and stored. The lack of an outlet leads to a slow but continuous increase of the stored waste volume.

[9] See also the HCTSIN recommendation of 7 November 2008 on the radio-ecological monitoring of the water around the nuclear facilities and on the management of old radioactive waste storage sites at the following address : www.hctisn.fr

Radioactive waste storage sites classified facilities classified for the protection of the environment (ICPE)

The RHODIA site at La Rochelle

Rhodia stores on its site at La Rochelle various types of radioactive waste originating from the processing of monazite, and then beginning in 1994, from the processing of rare earth concentrates. The site is authorised as a facility classified for the protection of the environment. Rhodia has approximately 13 700 t of waste in the form of :

- radium-bearing residues, denoted RRA (approximately 1850 Bq/g in alpha and beta activity in the year 2002) : 160 t at La Rochelle, most of the RRA being stored at Cadarache (5120 t) ;
- common solid residues, denoted RSB (approximately 75 Bq/g) : 8400 t at La Rochelle.

This waste, which is qualified as low level and long lived, is part of the inventory of waste intended for the ANDRA radium-bearing waste disposal project.
RRA waste is stored on the Cadarache site (ICPE 420 and 465 called "thorium cells") and RSB waste on the Rhodia site at La Rochelle in a building (BAT135).
In conformity with its ministerial order of authorisation, Rhodia takes dose rate measurements at the site limit, activity measurements in rainwater, and discharge measurements in radon. The evaluation of the dose for a person of the most exposed reference group is on the order of 0.4 mSv per year. Rhodia also radiologically monitors the water table located directly underneath the site according to the modalities of a prefectoral order of 30 June 2006. The monitoring of the water table directly underneath the disposals did not disclose any impact due to thorium, but a very slight tracing with uranium (30 µg/l) was read on some piezometers. However, no impact was sensed in the drinking water of this water table.

The CEZUS Company Site at Jarrie

Cézus, a subsidiary of AREVA NP, manages all the zirconium metallurgy phases, from the conversion of zircon (the original ore) up to the production of a wide variety of zirconium based products (tubes made of zirconium alloy, rods and metal strips for nuclear reactors). On the Jarrie site, Cézus produces approximately 2 200 tonnes of zirconium sponge per year. The zirconium sponge manufacturing process generates various types of enhanced natural radioactivity waste :

- Radium-bearing waste for an annual production of 150 tonnes. This waste is included in the inventory made for the future LL-LL disposal centre. It is currently stored on the Jarrie site (current stock approximately 2 000 tonnes) in a dedicated building consisting of six cells of 1000 m² each equipped with retention basins. The waste is bagged and then conditioned in 220-litre metal drums stacked three-levels high on plastic pallets. The building is sized to ensure a storage up to 2015. Until 1991, this waste (a total of 2 100 tonnes) was disposed of in a class 2 disposal centre for non dangerous waste at Vif in the Isère department. The cells in which this waste has been disposed of are clearly identified. From a monitoring of the site : measurements (radium in the water and radon) do not disclose any radiological impact from the disposal.
- Very low radioactive sludge originating from the effluent processing plant for an annual production of 800 to 900 tonnes. This sludge is stored in bulk in a building equipped with a leak-tight surface with drainage and recovery of the leachates before elimination to a class 1 disposal centre for dangerous waste at Bellegarde in the Gard department based on the circular of 25 July 2006 on the acceptance of concentrated or enhanced natural radioactive waste in waste disposal centres.
- Graphite chlorination tubes for an annual production of approximately 10 t. A part (86 m^3) was eliminated to the Morvilliers disposal centre operated by Andra (Very Low Level Disposal Centre - VLLDC) in 2007 (corresponding to several years of production). The remaining stock should be eliminated in 2009 toVLLDC.
- The sublimator's stainless steel pipes for an annual production of approximately 10 t. The manufacturer envisions decontaminating them and, depending on their radiological activity after decontamination, either recycle them at a manufacturer or eliminate them as waste in a dangerous waste disposal centre or toVLLDC.

The results of the measurements taken within the framework of the ministerial order of 25 May 2005 related to professional activities, which implement raw materials containing naturally radionuclides not used because of their radioactive properties, are around or below the detection limits of the used methods.

The COMURHEX Site at Malvési

The fuel cycle begins with the extraction of the uranium ore and its conversion by the Comurhex Company into UF4 at Malvési and then into UF6 at Pierrelatte in view of its isotopic enrichment into uranium 235. Most of the liquid effluents are generated during the ore purification phase on the Malvési site. These effluents are conveyed after neutralisation to an area for processing by lagooning located on the site and covering approximately twenty hectares, which includes settling and evaporation basins. The evaporation basins behave like salt marshes, letting the water evaporate naturally under the effect of the sun and wind.

The Comurhex Company of Malvési has 11 lagooning basins :

- 5 settling/evaporation basins, containing or designed to contain solid deposits after settling of the effluents originating from the facility's processes ;
- 6 evaporation basins designed to receive only the liquid fraction of the effluents.

Today, approximately 300 000 tonnes of sludge are stored on the site, mainly in the basins B1 and B2. This sludge has a mass activity, mainly in Th^{230}, on the order of 200 Bq/g. Artificial radionuclides are also present in the basins B1 and B2 due the past industrial activities of the facility. The operator estimates that the residues of the old sulphur mine located underneath the basins B1 to B6 and whose volume is estimated at approximately one million m3 are probably contaminated in part. Moreover, the recovery of the nitrates concentrated in the basins B7 to B12 should generate more than 75 000 tonnes of residues.

Important investments are assigned for the period 2008-2015 : their purpose is to modernise the Malvési facility (Comurhex II project) and process the lagooned effluents (future of the lagoon zone and, in particular, processing of 100 000 tonnes of nitrates present in the evaporation basins). For the liquid effluents, the new facilities provided for within the framework of the Comurhex II project should allow evaporating a part of the effluents and recycling the nitric acid, which will reduce the volume of the effluents to be evaporated and the produced quantity of nitrates. The processing facility by evaporation of the liquid effluents should allow reducing the lagooned volume of liquid effluents by a factor of 2. The mass of residues conveyed into the settling basins will not be modified.

Radio-ecological studies conducted in 2007 and 2008 by IRSN disclosed a tracing of the soils and the plants sampled nearby the site under the prevailing winds, as well as the channels and basins located downstream from the current and historical discharges. Calculations performed by IRSN to evaluate the doses received in the plant's environment by inmanagement of tagged products show that these doses are essentially due to naturally present radionuclides (potassium 40).

AREVA is currently conducting studies to define and apply solutions to limit the environmental impact of the storage. These studies must be finalised by the beginning of 2010 to be submitted to authorities for approval.

2.1.3. Storages of recoverable materials

This section describes the storages of reusable materials ; the perspectives of reusing these materials are presented in 2.2 and 3.2.

The enrichment process with the uranium isotope 235 implements uranium in the form of uranium hexafluoride (UF_6). This chemical form is used for its physical properties, which allow using it in the gaseous state under temperatures and pressure conditions in agreement with the technical constrains of the used enrichment processes (gaseous diffusion and centrifugation).

Uranium hexafluoride is exclusively conditioned in special standardised containers ; this conditioning method is used in all the facilities and for each of the activities where uranium is in the form of uranium hexafluoride, namely :

- feeding with natural uranium and withdrawal of enriched uranium, as well as depleted uranium, from the enrichment plants ;
- storage of uranium on installed enrichment plant bases and their ancillary facilities (facilities for isotope adjustment, material's sampling, preparation of the material's shipments to nuclear electric power company customers) ;
- material transports to customers or service providers.

The depleted uranium originating from the enrichment plants pending reusability (cf.2.2) is forced to be stored for a longer duration. In order to simplify the safety management of the depleted uranium storage facilities, it was decided to transform it into a solid, stable, non fuel, insoluble and non corrosive material, a uranium oxide (U_3O_8), which comes in the form of a black powder. This oxide is comparable to the natural uranium oxide present in exploited lodes. This operation is performed in the AREVA NC defluorination plant at Pierrelatte.

This depleted uranium in the form of U_3O_8 is conditioned in sealed metal containers with an average capacity on the order of 7 tonnes of uranium. These containers can be stored on two sites. Approximately 130 000 tonnes of uranium in the form of U_3O_8 are stored on the Tricastin site either in buildings dedicated to the storage of depleted uranium or in storage buildings for recycled uranium where they contribute to attenuating the gamma dose rate originating from the reprocessed uranium. The rest, approximately 100 000 tonnes, is stored in dedicated buildings on the Bessines site. These buildings provide a protection against external aggressions (rain, wind, etc.) and limit the industrial operator's interventions to control and monitoring operations. This industrial option allows globally limiting over the entire process the exposure of the interveners to ionising radiation.

The reprocessed uranium (URT) is conditioned in reprocessing/recycling plants (La Hague and formerly Marcoule) in the form of uranyl nitrate. For the non re-enriched part (cf 2.2), the nitrate undergoes a denitration and oxidation process which transforms it into a stable oxide U_3O_8 to facilitate its storage. This conversion stage is performed at Pierrelatte. The reprocessed uranium is then conditioned in the form of U_3O_8 in 220 L metal canisters with an average capacity on the order of 250 kg of uranium. These containers are stored on the site at Pierrelatte in special storage buildings. Approximately 21 000 tonnes of URT are stored today in this form at Pierrelatte.

Taking into account the various chemical forms (U_3O_8 and UF_6), a total of 254 820 tonnes of depleted uranium was stored in France on 31 December 2007. On this same date, 21 180 tonnes of reprocessed uranium was stored (except for small amounts of uranyl nitrate still not converted to date).

Moreover, Rhodia is storing at La Rochelle :

- suspended matter (MES) originating from the processing of chemical effluents (not radioactive) effective since August 1994 following the shutdown of the exploitation of monazite. MES are titrated on the average with 25 to 30 % rare earth oxides corresponding to approximately 7 000 tonnes of produced rare earth oxides. The MES stock stored on the La Rochelle site on 31 December 2007 amounted to 21 672 tonnes ; today, the site still produces approximately 800 tonnes of MES each year ;
- raw thorium hydroxides and thorium nitrate : they originate from the processing of monazite before its substitution by other raw materials (complicated concentrates) and were produced between 1970 and 1987 for raw thorium hydroxide and until 1994 for thorium nitrate. The stored quantities amount to approximately 21 700 tonnes in the form of raw thorium hydroxides and 10 700 tonnes in the form of thorium nitrate. On 31 December 2007, this total stock corresponded to 7 134 tonnes expressed in equivalent ThO_2 (thorium dioxide).

Since the Rhodia Company does not have available today reusage or elimination management solutions for its materials and its waste, it must continue to store these substances on its site.
The suspended matter is stored in bulk on a tarpaulined leak-tight area.
The thorium nitrate is stored in a building. On the other hand, the raw thorium hydroxide has been stored for a long time on three outdoor areas, but they were re-engineered to allow for the addition of

biological protections in the form of concrete plates, as well as a metal structure building, which is participating in the protection of the drums. Adding radiological protections has allowed reducing exposure to workers and the population. A small quantity of raw thorium hydroxide (2 000 t) is stored in bulk in the thorium cells.

2.1.4. Evaluation of the adequacy between the storage capacity and the estimated inventory of waste

Chapter 3 of the 2009 National Inventory of Radioactive Materials and Waste evaluates with respect to the waste stocks until the end of 2020 and end of 2030 the storage capacities for the waste for which the final solution is still at the project stage (HL, IL-LL, radium- and tritium-bearing waste). The inventory specifies, in particular, the total storage capacities on the producer sites, the occupied capacities at the end of 2007, as well as the extension capacities provided for, if necessary, to cover future needs. In addition, Annex 4 of the Inventary presents, with respect to these capacities and the estimated waste volumes, a first evaluation of the storage needs for the HL and IL-LL waste packages on the production sites before the commissioning of the deep repository scheduled for 2025. This evaluation shows that the storage facilities on the production sites should allow, provided the necessary extensions are made, responding as early as 2015 in terms of capacities and lifetimes to the needs anticipated today and until the deep geological repository goes into operation, which is scheduled for 2025.

A more detailed analysis of the adequacy between the storage capacities and the prospective waste volumes is given in the annex essentially for HL and IL-LL waste. Key points are summarised hereafter.

Storage of vitrified HL/IL-LLwaste packages of La Hague

The three storage facilities (R7, T7 and E-EV-SE) have a cumulative capacity of 2 174 m3, which will be saturated around 2013. AREVA conducted in 2006 a study and then began construction of an E-EV-SE extension which will be operational in 2012 and will raise the capacity to 3 648 m3. Other similar capacities will be necessary beginning in 2022 (see section 3.1.2). Production will continue up to the vitrification of the rinsing effluents, which will be generated after the final decommissioning of the UP2-800 and UP3 plants envisioned for 2040.

Storage of vitrified HL/IL-LLwaste packages of Marcoule

The capacity of the Marcoule vitrification workshop warehouse (665 m3) is sufficient to accommodate all the productions provided for at Marcoule, which will be completely accomplished before 2020. The request to keep the storage facility in operation until the packages have been recovered for disposal in the deep geological repository, when it becomes effectively operational, is being evaluated by DSND.

Storage of spent fuels to be disposed of without preliminary processing

Some spent research fuels will not be processed and are to be disposed of after conditioning. At Cadarache, these fuels are progressively conditioned in metal claddings in the STAR workshop and are stored in the CASCAD facility, which was placed in operation in 1990, for an estimated operational duration of 50 years. The part reserved for civil fuels in this facility has a capacity of 4 770 packages. The total volume of already conditioned spent fuel packages represents approximately 51.5 m3 (3 090 packages). In 2030, this conditioning will be terminated and the total volume will be 74 m3 (4 374 packages). Based on the data available today, the CASCAD capacity seems sufficient to satisfy the storage needs for unprocessed fuels until the final decommissioning (CDE).

Storage of the compacted cladding waste of La Hague

The storage facility for compacted hulls (ECC) placed in operation in 2002 for an estimated operating duration of 50 years has a capacity of 3 806 m^3. It is modularly designed with a land reserve which would allow constructing, if necessary, up to 6 modules equivalent to the existing module. The ECC should reach saturation around 2025.

The production of compacted hull and end-cap packages will subsequently increase with the beginning of the processing at the industrial scale of the accumulated MOX fuels in dilution with the UOX and URE fuels.

The disposal of packages when the deep geological repository goes into operation would allow, in principle, optimising the capacity of an ECC facility's extension (see section 3.1.2). The ECC facility's extension should be studied with respect to the CSD-C volumes produced by the reprocessing of UOX, MOX and URE, as well as the disposal date of the packages.

Storage of the packages of sludge and organic and metal alpha-emitting technological waste of La Hague

These packages occupy today a volume of approximately 2 600 m^3. They are stored in the halls, with a capacity of 4 760 m^3, of the S building of the STE3 plant, which was placed in operation in 1987 for a scheduled operation up to 2040. In 2020, the volume will attain an estimated total of 6 090 m^3. Additional required storage capacities will be provided by the destorage and storage extension units of the D/E – EB bituminised drums of the ES building which were constructed in 1995 for a scheduled operation up to 2040. This facility located in the extension of the S building has a capacity of 6 426 m^3. In 2030, the total capacity of the S and ES buildings, which is 11 186 m^3, will be, in principle, sufficient to store the productions of the previous packages, whose total volume will attain 9 533 m^3. The sludge and alpha-emitting technological waste packages conditioned at La Hague do not generate, therefore, any need for a new storage capacity before 2040. Even though it may be envisioned to dispose of the bituminised sludge packages around this date, the compacted alpha waste packages should probably still have to be stored pending the decay of their production of radiolysed hydrogen in a second generation facility which would have to be created (see section 3.1.2).

Storage of cemented packages of solid operating waste, powdered waste, and hull and end-cap waste of La Hague

The solid waste storage facilities have a total capacity of 14 331 m3. They are scheduled to remain in operation up to 2040. This capacity should be sufficient up to then to accommodate the estimated production, which will cause an increase in the IL-LL package volume from 9 012 m3 in 2009 to 11 125 m3 in 2030.

Storage of the bituminised sludge and solid waste packages on the Marcoule site

The bituminised sludge drums produced since 1996 are stored in the casemate 14. The part of the drums belonging to the IL-LL management route will represent a volume of 518 m3 at the end of 2014, the date a new conditioning process will be installed for the cementation of the sludge. Future needs for the storage of these drums will depend on the operation perspectives for the time the casemate 14 remains on the Marcoule site and the time to dispose of them.
Within the framework of the recovery of 58 000 bituminised sludge drums produced before 1996 stored in pits in the North zone and in the first 13 casemates of the STEL, a multipurpose interim storage facility (EIP) was placed in operation in 2000 to store 380 L drums called EIP drums. It has a modular design and currently consists of two cells[10]. It is anticipated today to operate for 50 years. A first stage consisted of recovering and over-packing in EIP drums the 6000 drums of the North zone. The recovery of the drums of the casemates 1 and 2 is in progress. The current capacity of the EIP is expected to be saturated around 2016 with a volume of 4 370 m3, that is, 11 500 packages (linked to the IL-LL and LL-LL processes). A new capacity should thus be placed in operation in order to pursue the recovery programme. New EIP modules are scheduled to be constructed in order to purse the recovery programme of old bituminised sludge drums and allow starting in 2016 the recovery programme of process and cladding waste stored for uncladding. All these waste packages (sludge and solid waste) would represent by 2025 a total volume on the order of 6600 m3. Starting from this date, the volume of the waste stored at EIP could become stable if the shipment flow to the disposal would attain approximately 800 m3 per year. Destorage would be envisioned starting from 2050. The study of another, more favourable strategy for the disposal resource management plan is present in section 3.1.2.

Storage of highly irradiating IL-LL waste packages on the Marcoule site

The operations of dismantling, recovery and conditioning of old waste will produce highly irradiating IL-LL waste packages for which no disposal facility exists. For the Marcoule site, the volumes of this category of waste produced by the dismantling of the PHENIX reactor (the most active waste), as well as the recovery of the fuel cladding waste processed in the Marcoule pilot workshop (APM), would represent approximately 253 m3. To satisfy this need, CEA scheduled the construction of the DIADEM facility, which will be placed in operation by 2014 (see section 3.1.2). In addition, this new facility will allow storing the highly irradiating waste originating from other CEA sites (Fontenay, Saclay, Grenoble).

Storage of lowly irradiating waste packages on the Marcoule site

In 2006, CEA placed in operation at Cadarache radioactive waste conditioning and storage facilities (CEDRA) : two buildings offer a capacity of 4 450 m3 for lowly irradiating (LI) waste packages. At the end of 2008, the volume occupied in CEDRA was 533 m3. The current LI storage capacity of 4 450 m3 will not be sufficient to manage all the packages to be produced (or to be removed from INB 56). In fact, the estimated cumulative volume of LI waste around 2030 will be approximately 8 300 m3. Also, CEA envisions increasing the LI storage capacity of CEDRA to 10 000 m3 by constructing section 3 around 2014. It should be noted that the storage capacities to be reserved on CEDRA for the old packages removed from INB 56 will depend on the complexity of the controls and reconditionings which will have to be implemented and the spreading out of the operations over time.

Storage of moderately irradiating IL-LL waste packages on the Cadarache site

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10 Its extension can be envisioned up to 16 cells, increasing the total capacity to 33 880 m^3.

At the beginning of 2009, the cumulative volume of MI waste stored on the Cadarache site was 1 052 m3. It will attain 1 595 m3 by 2030. The current capacity of CEDRA (825 m3) will not be sufficient to satisfy the needs. CEA envisions increasing this capacity : after the construction of section 3 of CEDRA, it will be raised to 1 650 m3 ; an additional section - section 4 - would allow raising the capacity to 2 350 m3.

Storage of other waste packages on the Cadarache site.

Radium-bearing lead sulphate packages, large capacity containers (1 800 or 1 000 litres) with solid waste and filtration sludge, and "source blocks" are currently stored in INB 56. They are terminated productions which represent a volume of approximately 1 275 m3. To remove these packages linked to the IL-LL management route from INB 56, a new storage capacity corresponding to this volume will be necessary. CEA envisions constructing an "interim building" in section 2 of the CEDRA facility.

Storage of IL-LL waste packages on the CEA's Valduc site

The Valduc liquid effluent processing plant produces coprecipitation / filtration sludge and concentrates. From 1984 to 1995, this waste was cemented in 220 L metal drums linked to the IL-LL management route. The total volume of the IL-LL packages is 81 m3. They are stored on the site. The processing of recyclable materials produces effluents containing americium, plutonium and uranium that CEA plans to vitrify after 2020. These IL-LL packages will also be stored on the site. By 2030, the total volume will attain 10 m3.

Storage of EDF activated waste packages on the Bugey nuclear power plant site

Beginning in 2014, activated waste produced by the dismantling of the EDF nuclear reactors of Creys-Malville, Brennilis, Chooz A, Bugey, Saint-Laurent-des-eaux and Chinon, as well as the internals removed from electronuclear reactors in operation : control rod clusters and "poison" clusters will be conditioned in the ICEDA facility to be constructed on the Bugey site. EDF plans to endow the ICEDA facility with two storage halls, each having a capacity of approximately 2 000 m^3. One will accommodate up to 1 000 packages of IL-LL and LL/IL-SL waste in a C1PG container. The other will accommodate in a first period 300 LL/ILSL caissons of 5 m^3 and 10 m^3 and graphite waste packages. Up to 2020, the capacity of one hall should be sufficient to accommodate the IL-LL packages in the C1PG container, provided the volume of the LL/IL-SL waste packages in transit to Low Level and Intermediate Level Disposal Centre (LL/ILDC) remains below 250 m^3. By 2030, the capacity of the second storage hall will be in part used for the IL-LL waste packages in a C1PG container, which means that around this date the volume of the LL/IL-SL and LL-LL packages will be limited pending shipment to their respective disposal.

Storage of miscellaneous radioactive and radium-bearing waste

To manage radioactive waste outside of the electronuclear sector, Andra has storage capacities on the AREVA/SOCATRI and CEA facilities (INB 56 at Cadarache, INB 72 at Saclay) for the diffused nuclear sector waste originating mostly from the LL-LL management route. These storage capacities are limited in terms of the types of waste that they can accept. Thus, Andra is not able to store either Ra-Be radioactive sources or sources in a liquid or gaseous state, and so cannot collect them. There are also time limits on the acceptance of irradiating objects which are sometimes greater than needs. Finally, the CEA facilities are being considered in dismantling and destorage projects (see previous section). Also, Andra is studying new storage solutions for the management of waste from the nuclear sector and for the collection and grouping of waste from the hospital/university sector (see section 3.2.3). Moreover, radium-bearing waste linked to the LL-LL management route is stored by Rhodia, Cézus and CEA. Andra will analyse in concertation with the operators the adequacy of the available storage capacities for the estimated waste inventory and the possibilities of disposing of LL-LL waste (cf. 3.1.2).

2.2. Long-term management of reusable materials

As specified in section 1.1.1, the Environmental code defines a radioactive material as a radioactive substance for which a subsequent utilisation is provided for or envisioned, if necessary, after reprocessing.

Radioactive material exchanges with foreign countries take place at several phases in the fuel cycle, even though France controls all the phases. In particular, natural, depleted and enriched uranium are exchanged because by diversifying uranium supplies, it is possible to limit the risks. In fact, it would be irresponsible to entrust the French supply of enriched uranium to only one plant, even French ; this reasoning is also true for the fuel conversion and fabrication phases. Any industrial facility can encounter operational failures which can interrupt production. To avoid any break in the supply route, EDF, which relies mainly on AREVA, also has contracts with Urenco (enrichment company installed in the Netherlands, England and Germany) and Tenex (company installed in Russia). These two companies like AREVA have harnessed enrichment techniques for many years. In addition, the industrial process used by Urenco and Tenex is known (ultra-centrifugation), and has been adopted by AREVA, which will implement it in the framework of the George Besse II plant under construction at Pierrelatte.
An assessment of the flows across the borders is presented hereafter. It should be noted that the figures have been coming from the declarations made at the EURATOM level ; the nuclear operators may have a different accounting approach, which can lead to a different vision, even though the underlying physics are identical. Therefore, these figures should be handled with caution.

Pluralism 2006-2009	**Importation**	**Exportation**	**Bilan**
Depleted Uranium	15 163,5	28 725,9	-13 562,3
Enriched Uranium at 20% and more	0,1	1,5	-1,4
Enriched Uranium at 20% and less	6 405,9	6 559,0	-153,1
Natural Uranium	38 814,8	18 960,2	19 854,7
Plutonium	1,9	9,2	-7,3
Thorium	0,1	11,6	-11,5

Annual average flow	**Importation**	**Exportation**	**Bilan**
Depleted Uranium	3 790,9	7 181,5	-3 390,6
Enriched Uranium at 20% and more	0,0	0,4	-0,4
Enriched Uranium at 20% and less	1 601,5	1 639,8	-38,3
Natural Uranium	9 703,7	4 740,0	4 963,7
Plutonium	0,5	2,3	-1,8
Thorium	0,0	2,9	-2,9

The PNGMDR 2007-2009 requested that owners of reusable radioactive materials for which no reusable processes had ever been implemented submit by the end of 2008 a report on the studies of reusable processes that they might envision. In line with this request, Areva, CEA and EDF submitted a joint study on their uranium-, plutonium- and thorium-bearing materials. Rhodia also submitted a study on the reusable processes for its suspended materials (MES), raw thorium hydroxides (HBTh) and thorium nitrates. The long-term management assessment for reusable materials described hereafter was drafted notably based on both of these studies.

Spent fuels

Most of the spent fuels present in France consist of light water reactor fuels either being irradiated in EDF reactors or unloaded from these same reactors and stored in a pool (on the sites of these reactors or in the AREVA plant of La Hague).

The reusability of civil spent uranium-based fuels through reprocessing/recycling at the La Hague plant and the recycling of the materials which are separated there is already a widely implemented industrial operation, in particular, for UOX fuels. Specifically for URE fuels (reprocessed fuels), the feasibility of processing them was demonstrated in 2006. Considering the nature of the separated materials, the reference industrial management route for spent URE fuels is recycling in 4th generation reactors.

In the case of spent civil plutonium-based fuels, 67.5 tonnes of spent MOX REP fuels have been processed in the plant at La Hague since its inception. Moreover, tens of tonnes of spent MOX RNR fuels have been processed at both La Hague and Marcoule. Thus, the feasibility of reprocessing MOX REP and MOX RNR fuels may be considered proven. In particular, considering the quantities of spent MOX fuels unloaded from the French installed nuclear base and the energy characteristics of the plutonium contained in them, the reference industrial management route for these fuels is recycling in 4th generation reactors. In this perspective, plutonium is currently maintained in the spent MOX assemblies until needed.

For research reactor fuels, a special technique implemented in the La Hague plant allows reprocessing fuels originating from certain reactors (IN2P3 at Strasbourg, and the reactors SILOE, SILOETTE, ULYSSE and SCARABEE). In addition, most of the "caramel" fuels (enriched uranium alloy sandwiched between two metal plates) currently used as fuels for other research reactors (OSIRIS, ISIS, ORPHEE) are to be processed : even though this processing campaign has still not taken place in the plant at La Hague, "caramel" fuels originating from the OSIRIS research reactor were processed at CEA Marcoule within the framework of a clean-up operation. It was possible to process 2.3 tonnes of UO2 and validate the concept. Finally, CEA has other types of spent research reactor fuels : fuels originating from the CABRI, PHEBUS reactors will be processed in the existing workshops.

Spent nuclear propulsion fuels are similar to "caramel" fuels, whose reprocessing does not pose any particular problem in terms of diffusion based on the previously mentioned feedback. It should be noted, however, that industrial reprocessing will necessitate new equipment in the plant at La Hague.

Thus, most of the spent fuels constitute reusable materials. Small quantities of spent research reactor fuels are, however, considered to be waste (for example, the fuels of the Brennilis EL4 reactor, OSIRIS oxide fuels and experimental rods and samples).

Uranium

Enriched uranium is used for the nuclear production of electricity.

Depleted uranium originates from uranium enrichment plants, which produce two flows of substances : on the one hand, uranium enriched with U 235, an isotope generally between 3 and 5% in content, which will be used to fabricate fuels and, on the other hand, uranium depleted in U 235, an isotope present with a content on the order of 0.4 % or less.
The three possible uses of this material are :

- Depleted uranium has been regularly used for the past few years as a MOX fuel support matrix (MOX is a composite fuel consisting of a mixture of uranium and plutonium and elaborated in France in the MELOX plant at Marcoule in the Gard department). This flow represents approximately one hundred tonnes per year (given that approximately 250 000 tonnes of depleted uranium are currently stored in France). Other utilisations consist of notably manufacturing counterweights for aircraft, but in small quantities.
- In addition, it may be cost-efficient to re-enrich depleted uranium to higher contents in case the current price for natural uranium rises or subsequent to an evolution in enrichment techniques. Thus, it can be envisioned that in the medium-term current depleted uranium stocks (denoted here "primary" Uapp) will be re-enriched over periods on the order of 30 to 50 years. New depleted uranium stocks, the secondary Uapp (with an enrichment ratio on the order of 0.1 to 0.2%), would thus be created. New technologies, such as laser uranium enrichment, could eventually allow an even more extensive separation, thereby producing the tertiary Uapp (with an enrichment ratio objective less than 0.1%).
- Finally, in the longer term, depleted uranium stocks will be reusable on a larger scale in fourth generation fast neutron reactors, which could be deployed by mid-century. In fact, this type of reactor can exploit much better the energy potential of the uranium isotope U 238.

Reprocessed uranium (URT) extracted from spent fuels constitutes approximately 95% of the spent fuel mass and always contains a significant part - on the order of 0.8 % - of the uranium isotope U 235. On request by the customer EDF, this reprocessed uranium can be sent to an enrichment plant to produce enriched recycled uranium (URE) which is used to fabricate nuclear fuels. Approximately 300 of the 800 tonnes currently originating per year from the reprocessing spent fuels are re-enriched ; today, they feed 4 reactors on the Cruas site. Beginning in 2010, in connection with increased processing (climbing to 1050 tonnes of processed spent fuels), approximately 1000 tonnes of reprocessed uranium will originate each year from the processing. Currently, all the French URT is re-enriched in Russia.
To date, reprocessed uranium cannot be enriched in France. In fact, natural uranium and reprocessed uranium cannot be simultaneously enriched in the same industrial line. The Georges Besse I plant is dedicated to the enrichment of natural uranium. The Georges Besse II plant, which is based on a different technology and is currently under construction, will be able to enrich in separate lines natural uranium as well as reprocessed uranium. EDF and AREVA are debating the issue in this sense.
In Russia, France or elsewhere, the enricher becomes the owner of the depleted uranium. At Pierrelatte, for example, AREVA takes possession of the depleted uranium originating from the uranium that it enriches, whether the uranium is EDF's or a foreigner customer's (American, German, English, etc.).

Eventually, when the Georges Besse II enrichment plant becomes operational, this enrichment operation may be performed in France. The recycling level depends mainly on the cost-efficiency of the URT (cost differential compared to natural uranium) and its role in secure supplies.

Utilisation over the long term of all these reusable materials is discussed above in section 3.2.2.

Plutonium

Like for uranium, the plutonium contained in the spent fuel assemblies is extracted during their reprocessing. A spent light-water uranium-based fuel contains today approximately 1% plutonium in mass. Once placed in solution, extracted and separated from the other materials contained in the spent fuel, the plutonium is purified and conditioned at AREVA NC La Hague in the stable form of PuO_2 oxide powder (workshops R4 and T4). Plutonium recycling is done today in the MOX fuel, which consists of depleted uranium as the support and plutonium in the form of $(U,Pu)O_2$ oxide powder pellets.

In France, the MOX fuel used by EDF contributes to approximately 10% of the national nuclear production of electricity. Thus, approximately 10 tonnes of plutonium are annually recycled, that is, the entire flow originating from the EDF fuels processed in the La Hague plant by AREVA NC.

On the longer term, plutonium may also be used to start fourth generation reactors. The analysis of this potential utilisation is given in section 3.2.2.

Thorium

Thorium can be transmuted by neutron capture into the fissile uranium isotope U 233. A "thorium cycle" using thorium as a fuel may thus eventually emerge, but not before several decades considering the research and development still to be done.

Areva and CEA have thorium in the form of nitrate stored on the CEA Cadarache site and the vast majority belongs to Areva. The joint study submitted by Areva, CEA and EDF at the end of 2008 concludes that the feasibility of thorium reusability is proven (filed patents, extensive R&D acquired with prototypes).

In the case of HBTh (containing thorium, uranium and rare earth oxides) and thorium nitrate, the Rhodia study concludes notably that the main phases of the process have already been exploited industrially and that the economic assessment of the reprocessing shows that a price of ten euros per kg of ThO_2 is sufficient for the investment to be profitable.

The conclusions of these studies and the reusable and unreusable nature of the thorium-bearing materials are discussed above in section 3.2.2.

Suspended matter

Rhodia radioactive materials also include suspended matter (containing rare earth oxides and traces of thorium and uranium). The study submitted by Rhodia concludes with the technical/economic feasibility of the reusability of this suspended matter. The reusable nature of this suspended matter is also discussed in section 3.2.2.

2.3. Long-term waste management : disposal centres dedicated to radioactive waste

Two radioactive waste management routes implemented via dedicated disposal centres already exist : the very low level (VLL) waste management route and the low or intermediate level and short lived (LL/IL-SL) waste management route.

2.3.1. The very low level (VLL) waste route

The build-up of dismantling operations in France in the upcoming years raises the question of the availability of long-term management routes for the produced waste. The major part of this waste will be produced after the progressive shutdown of 58 pressurised water reactors currently in operation. However, France is already confronted with the dismantling of 9 power production reactors (including 6 of the graphite moderated, gas cooled natural uranium type), the first reprocessing plant at Marcoule, and other facilities, notably CEA reactors or laboratories.

According to French regulations, the waste produced in a part of a nuclear facility where it is liable to be contaminated or activated must be managed by special management routes to ensure a sufficient traceability, regardless of its level of activity. In fact, based on the regulations[11] a study has to be made (the so-called "waste study"), including a "zoning" of the facility, submitted for approval by ASN for the INBs and by DSND for the INBSs, which allows distinguishing two types of zones. Zones liable to lead to the production of radioactive waste are called "nuclear waste zones" ; the other waste is conveyed to the conventional waste management routes after it is checked to ensure it is not radioactive. A large part of the waste originating from the "nuclear waste zones" does not necessitate any special confinement arrangement because its activity is very low ; sometimes its radioactivity is only potential. A safe and economic disposal management route was, therefore, dedicated to it with the creation of a very low radioactive waste disposal centre. The VLL waste disposal of Morvilliers in the Aube department has been operational since the summer of 2003.

While the radioactive dangerousness is very low for the VLL waste, the chemical dangerousness for some VLL waste may be high ; this disposal is based on the technical concepts of class I chemical waste disposals (dangerous waste). The disposal is a surface disposal with cells dug in the clay soil and the bottom arranged to "collect" any infiltrated water throughout the disposal lifetime. Thus, it is isolated from the environment by a structure consisting of :

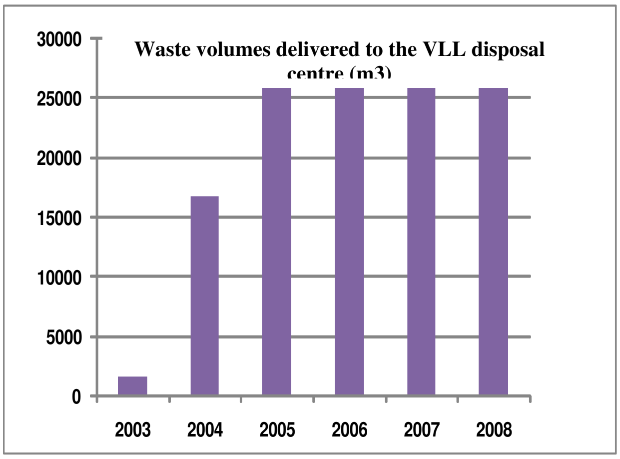
- a synthetic membrane surrounding the waste and associated with a control system ;
- a thick clay layer under and on the sides of the disposal cells ;
- a cover also made of clay laid on top of the waste.

During the operation of the centre, the waste is placed in a zone under movable roofs to protect it from rainwater. In the long term, the long lived radioactive elements and chemical substances will be confined by the retention properties of the clay formation.

At the end of 2008, the total disposal volume was approximately 115 700 m^3, that is, 17.8% of the authorised regulatory capacity (650 000 m^3).

Since the placing of the centre in operation, the needs expressed by waste producers have led to the modification of the disposal cell dimensions in order to accommodate more important quantities of waste. The annual disposal capacity proposed by Andra to producers has increased from 26 000 m^3 to 32 000 m^3 (in 2009) per year.

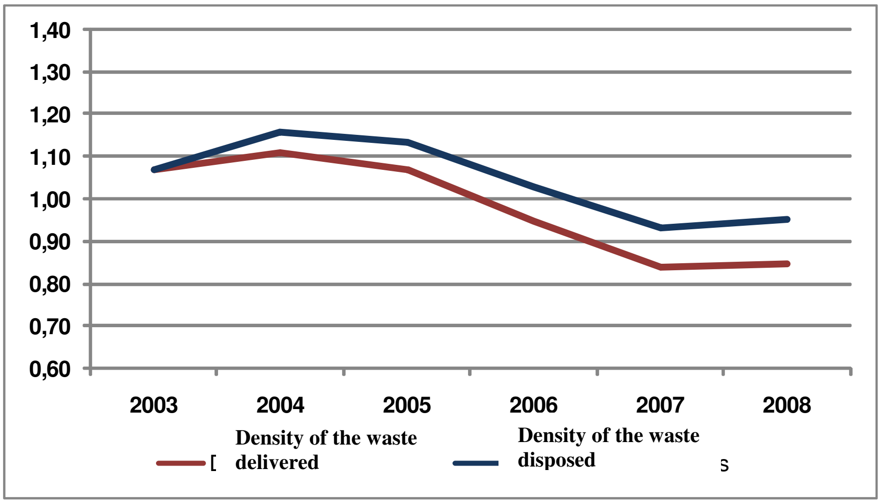
[11] Ministerial order of 31 December 1999 modified fixing the general technical regulations intended to prevent and limit nuisances and external risks resulting from the operation of basic nuclear facilities and ministerial order of 26 September 2007 fixing the general technical regulations intended to prevent and limit nuisances and external risks resulting from the operation of secret basic nuclear facilities.



Waste volumes delivered to the VLL disposal centre

And yet, the acceptance of some dangerous waste poses a problem. This is the case notably for waste containing asbestos, which necessitates special precautions to place it in a cell and whose total disposable quantity is limited by long-term safety considerations.

Moreover, the density of the waste delivered since it went into operation is much less than the density taken into account in the design of the centre (1,3). This increases the consumption of the disposal capacity in volume. This situation is amplified by the fact that the producers use the centre's compacting facilities ("scrap metal" press) less due to notably the retained technical and economic criteria. The Andra national inventory indicates based on the reference scenario and hypotheses communicated by the waste producers that the centre's capacity should be saturated in 2020. Optimisation lines of this capacity are discussed in section 3.3.1.



Density of the waste delivered and disposed of at the VLL disposal centre

2.3.2. The Low and Intermediate level and short lived (LL/IL-SL) route

The Manche disposal centre

The low or intermediate level and short lived waste packages were received at the Manche disposal centre (CSM) until 1994. Since it was placed in operation in 1969, 527 000 m3 of waste packages have been disposed of here. The centre was covered between 1991 and 1996 with a covering which is made leak-tight by a bituminous membrane. The transition into the monitoring phase was formalised by the decree of 10 January 2003.

In conformity with the prescriptions of this decree, a report on the covering's behaviour was submitted to the National Safety Authority (ASN) at the end of 2008, and the ASN conclusions will be made known by the beginning of 2010. The main problem encountered concerns the long-term stability of the slopes of the cover which are too steep due to the limitations of the centre's current ground surface footprint. This could eventually necessitate enlarging the land surface footprint of the centre.

The persistant presence of tritium, though decreasing, is observed in the water table underneath the centre and in the surrounding rivers. It is linked to the disposal of tritium-bearing waste in the CSM during the 1970s. Evaluations show, however, a very low impact on the environment.

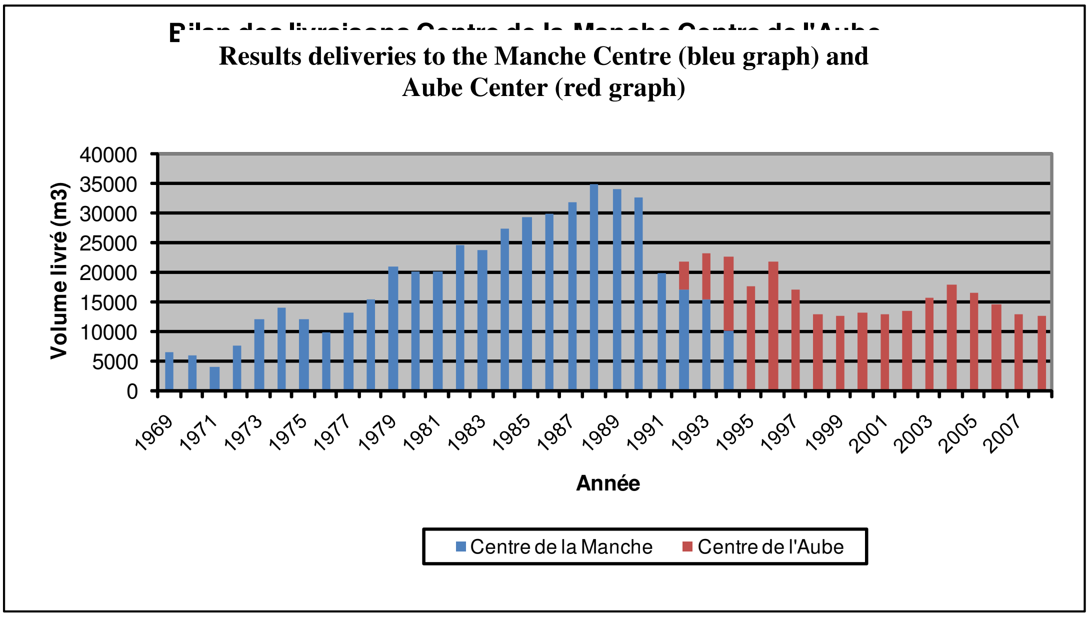
The Aube disposal centre

The Aube disposal centre (LL/ILDC) took over from CSM beginning in 1992. It benefits from the feedback from CSM and the safety rules which were established there during the 1980s. The principle of the disposal consists of confining the radioactivity in packages and disposal structures to let it decay for several hundred years. The radioactive content of the waste in long lived radioelements must be sufficiently small so that the disposal's impact is acceptable after 300 years of monitoring even in case the structures and packages are degraded.

The packages are disposed of in concrete compartments protected by movable metal frameworks which move at the rate of the exploitation. The packages are cemented or immobilised by gravel in the structures depending on whether the packages have concrete or metal envelopes. Once filled, the structure is closed by a slab and a plastic material is applied to make it impermeable to rainwater.

Andra has formalised its requirements concerning waste conditioning in technical specifications. The package manufacturing processes are approved by agreements and monitored by Andra.

At the end of 2008, 220 000 m^3 of waste packages were disposed of at LL/ILDC, representing approximately 22% of its authorised capacity. The annual flow of deliveries is currently around 12 000 m^3 of packages, which corresponds to half the dimensioning flow. Efforts to reduce the production of waste at the source in nuclear facilities helped significantly extend the centre's lifetime initially expected for 30 years and which should be extendable up to 2040-2050.



As for the radiological capacities, 19 radioelements are under rules of limitations. Likewise, the global alpha activity accounted for 300 years is limited. At the end of 2008, the parts of the capacities consumed for [illegible]ess than the capacity consumed in volume (22%), except for chlorine 36, [illegible]than 88% of its capacity. The capacity retained for this radioelement [illegible]ears was based on the anticipated acceptance of the graphite waste stored [illegible]hutdown.

The LL/ILDC [illegible]welve standardised packages from the viewpoint of their geometry. Very quickly after it was placed in operation the question was raised about the possibility of storing massive parts without having to cut them to condition them in standard packages. Such an option can have an economic interest for the waste producer ; it can also reduce worker exposure to ionising radiation on the worksites. So, ANDRA already took charge of packages which were not within dimensional standards either in standard structures or in dedicated structures endowed with special handling and conditioning means. Consequently, the LL/ILDC is accommodating in specialised structures a total of 55 replaced tank covers of pressuirsed water reactors.

2.4. Long-term waste management : other existing management methods

2.4.1. Mining residues and waste rocks

In France, uranium mines were exploited between 1948 and 2001, resulting in the production of 76000 tonnes of uranium. Exploration, extraction and processing activities concerned approximately 210 sites in France distributed over 25 departments. The ores were processed only in 8 plants, but the residues originating from the reprocessing are disposed of on 17 sites. Today, the management of these products is an in-situ management considering the large quantities of waste produced calling for the set up of provisions to reduce the risk over the long term. This is why Areva had been asked in the previous PNGMDR to evaluate the long-term impact of the mining residues disposal sites.

2 categories of products originating from the exploitation of the uranium mines can be distinguished :

- Processing residues, which designate the remaining products after extraction of the uranium contained in the orel by dynamic or static processing. The residues correspond, in fact, to process waste (in the meaning of the Environmental code).
- Mining waste rocks, which designate the products consisting of soils and rocks excavated to access the mineralisations of interest. A distinction is made between "true" waste rocks, whose average uranium content corresponds to the characteristic content of the natural ambient background noise (located for instance between 15 and 100 ppm in the Limousin department), on the one hand, and "selective" waste rocks, which consist of mineralised rocks excavated during the exploitation of a lode, but whose contents do not economically justify a processing (the economic cut-off content for uranium is on the order of 300 ppm).

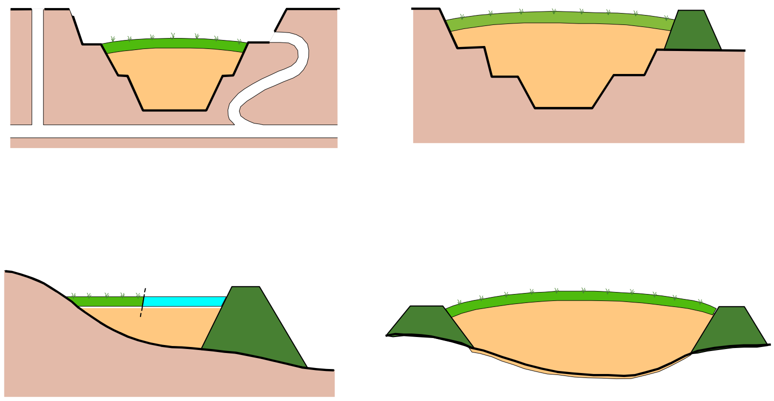
Orel processing residues and the disposal sites of these residues

The total quantity of residues can be evaluated at 50 million tonnes. The residues are disposed of on 17 sites. They are VLL or even in some cases LL waste. There are two types of ore processing residues which do not have the same mass activities :

- The ore processing residues of a low uranium content (on the order of 300 to 600 ppm of uranium) with a total average mass activity of 44 Bq/g (including approximately 4 Bq/g of radium 226). These residues originating from static leaching (approximately 20 Mt) are disposed of either in dumps or open-pit mines, or used as a first covering layer for the disposals of dynamic processing residues ;
- the ore processing residues of an average high uranium content (on the order of $1/100^{th}$ to 1% of uranium in French mines) with a total average mass activity of 312 Bq/g (including approximately 29 Bq/g of radium 226). These residues originating from dynamic leaching

(approximately 30 Mt) are disposed of either in old open-pit mines with sometimes a complementary dike, or in basins closed by an encircling dike, or behind a dike barring a talweg.

The disposal sites of mining residues were installed in the proximity of uranium mineral processing facilities. These disposals of one to ten hectares contain a few thousand to several miillion tonnes of residues.



Various types of mining residue disposals

With the progressive closing of mining works, the remediation of these disposal sites consisted of installing a solid covering on the residues to create a geomechanical and radiological protection barrier in order to limit the risks of intrusion, erosion, dispersion of the disposed products, as well as those linked to the external and internal (radon) exposure of the surrounding populations.

A monitoring system was set up based on the analysis of all the exposure and transfer pathways and on the identification of the population groups liable to be the most exposed group. Results show compliance to the added effective dose limit of 1 mSv/year. This check is faced with a practical problem of evaluating the added dose received by a member, taking into account notably the natural radioactivity already present locally and the failure to establish for the public a point zero at the opening of the mines. The necessity of reducing the required exposure level, notably in application of the principle of optimisation, is taken into account in the remediation phase.

From a regulatory viewpoint, the residues are considered to be industrial residues subject to the provisions of the 1st title of book V and notably article R 511-9 of the Environmental code related to the facilities classified for the protection of the environment. Most of the residue disposals come under the title 1735 of the classified facilities parts list.

Before these regulations became effective, these disposals were authorised by administrative acts taken under the mining code as dependencies of the mines.

Before the progressive closing of the mining sites, a series of actions were engaged by the administrations in order to define and apply a doctrine for the remediation of the disposals. In 1986, a technical instruction note related to uranium ore processing facilities defines the exploitation modalities applicable to these facilities. In 1993, the Barthélémy – Combes report titled "Low radioactive waste - Part 1 : Disposal of uranium ore processing residues" defined and elaborated, as requested by the Minister of the Environment, the objectives and the technical conditions for remediation the disposals. In December 1998, the Institute for Nuclear Safety and Protection (IPSN), succeeded by the Institute for Radiological Protection and Nuclear Safety (IRSN), elaborates the doctrine for remediation the residue disposals. In 2001, IPSN elaborates the methodology for the evaluation of the radiological impact of the uranium ore processing residue disposals[12] and BRGM the methodology for the evaluation of the stability of the dikes encircling certain residue disposals[13]. Finally, in 2003, the Ministry of Ecology and Sustainable Development confers to IRSN the national inventory programme of uranium mining sites, or "MIMAUSA" (French acronym for History and Impact of the Uranium Mines : Summary and Archives). A first inventory is published in April 2004 and its update in September 2007.

At the end of 2008, in application of article 4.5 of the Act no. 2006-739 of 28 June 2006 and article 10 of its decree of application no. 2008-387 of 16 April 2008, AREVA submitted a study on the long-term impact on health and the environment from the uranium ore deposit residue disposals, a study on the evaluation of the dikes behaviour, a study on the residues characterisation, as well as the recommendations associated with these studies (file of 30/01/2009).

The modelling methodology developed by AREVA to evaluate the long-term dosimetric impacts of the residue disposals include a normal evolution scenario and four altered evolution scenarios, namely : loss of integrity of the dike and the covering, development of a habitat above the disposal with or without a covering, construction of a road, and presence of a child playing on the excavated residues. This modelling is an important breakthrough for the evaluation of the long-term impact of the uranium ore processing residue disposals and corresponds to a first concrete application of the approach formalised by the circular of the Minister of the environment of 7 May 1999 related to the remediation of the uranium ore processing residue disposals. Moreover, the developed method is consistent with the approach implemented for the surface disposals of Andra, notably through altered evolution scenarios of the road worksite type or the residence on the disposal.

This methodology was applied by AREVA to nine disposals for ore processing residues of different size and geological context. Based on the results of the Areva studies, the dosimetric impacts liable to be received by the population in a normal evolution situation remain less than 1 mSv/year in the active monitoring phase and those imaginable for major degradation assumptions of the disposals remain less than a few tens of mSv/year.

The Areva study also indicates that the residues naturally evolve toward a mineralogical and chemical form which strongly limits the mobility of the uranium and the radium. Areva's evaluation of the dikes behaviour is consistent with the methodological framework defined by BRGM and indicates a good stability of the structures.

On the other hand, subsequent to these studies and in conformity with the engagements taken by the AREVA Company in the letter addressed to the Minister of State on 12 June 2009, Areva will continue to monitor these sites and is reflecting on the replacement of the water sheet covering from the Bois Noirs Limouzat site with a solid covering.

Moreover, the results of the reflections from the multi-party expert group on the uranium mining sites of the Limousin department (GEP Limousin)[14] are awaited. In fact, the GEP Limousin tried to specify the various administrative and operational functions involved in the monitoring (acquisition of knowledge, measurements, processing, control, application of ancillary services and obligations, history, etc.) and their necessary phasing in the short, intermediate and long term in order to control the sites. The final report of the work done by GEP Limousin scheduled for the end of 2009 should propose recommendations for the long-term management perspectives.

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[12] The Report IPSN-DPRE/SERGD/01-53 of November 2001

[13] The Report BRGM/RP-51068-FR of September 2001

[14] A multi-party expert group (GEP) was set up in 2006 by the Ministry of Ecology, the Ministry of Health and the Nuclear Safety Authority in order to intensify the dialogue and concertation efforts around the Limousin uranium mining sites. The GEP Limousin’s mission is to ensure the regular follow-up of the third-party appraisal of the operating assessment communicated in December 2004 by Areva NC and participating in its control. Four working subgroups were defined : source and discharge term, health and environmental impact, long-term regulatory framework, measures.

The mining waste rocks and the old mine extraction sites

It is important to avoid mixing up mining residues (which are strictly speaking process waste) and mining waste rocks, which are simultaneously extracted with the ore, but these rocks do not undergo any special mechanical or chemical processing (contrary to the ore).

At the beginning of the exploitation of uranium mines, the sterile mineral deposits were made available to neighbours who might have needed materials for backfilling. Beginning on the 1st of January 1984, COGEMA, in conjunction with the Central Service for Protection Against Ionising Radiation (SCPRI), set up a transfer register to ensure a better traceability of waste rocks. However, these registers do not give any indication for waste rocks reused prior to 1984. The modification of the mining code in 1990 more strictly regulated the management of materials originating from mining activities by making it mandatory to set up a management plan for solid products with a uranium content greater than 0.03%. This is the reason why in the history of uranium mining waste rocks could be transferred and reused in the surroundings of the mining sites on private individual properties or for other uses without the reusage conditions and sites and the transferred quantities being precisely recorded or systematically controlled.

Mining waste rocks are present in regions which have naturally outcrops of rock rich in natural natural radioactivity, and in which, therefore, there are already naturally analogous usage conditions for these rocks (notably, during infrastructure construction work). In addition, these regions are characterised generally by a high heterogeneity of natural radioactivity. Therefore, the problem of the waste rocks amounts partly to the problem of the protection of the population in regions with natural radioactivity higher above the average.

Actions are taken to draw up a list of all the ore extraction sites and all the historical data (presence of waste rocks, residues, etc.) or monitor the environment which can be associated with them. This is one of the objectives of the MIMAUSA programme.

As an extension of these actions and in order to resolutely pursue the management of the old uranium mines, the Ministry of Sustainable Development and ASN defined in the circular of 22 July 2009 an action plan consisting of the following work orientations :

- Inspect the old mine sites ;
- Improve knowledge about the sanitary and environmental impact of the uranium mines and monitoring ;
- Manage the waste rocks : learn more about their utilisations and reduce the impacts, if necessary ;
- Reinforce information and concertation.

The ore extraction sites (except for the mineral processing and disposal zones of the processing residues) rarely pose sanitary problems after they are re-engineered. In fact, the natural radiological impact could thus be lowered. However, it should be noted that some sites shelter lodes with waste rocks which may necessitate, in some cases, special monitoring or rehabilitation actions and even ancillary services to allow a suitable use of the site.

Some overflow waters must be monitored and even processed in order to precipitate the radioactive elements found in them and respect the discharge limits fixed in the prefectorial orders. However, it is possible that the sediments downstream from the sites be ″tagged″ due to the quantities of uranium and radium released in the hydrographic network. It should be noted that French sites do not encounter any major problems resulting from the acidification of the groundwater due to the mineralogical composition of the lodes and, therefore, do not raise any major problems in terms of the quality of the groundwater.

Generally, the waste rocks reused in the environment are not considered to have any sanitary or environmental impact (however, this must be verified site by site). On the other hand, it is assumed that radon concentrations may exist in buildings or structures erected on land backfilled with waste rocks (or in the immediate surroundings). The action plan defined in the circular of 22 July 2009 is an answer to this concern.
In addition, AREVA was asked to submit a generic study modelling the potential impacts in order to evaluate the exposure linked to the utilisation of mining waste rocks in the public area. The study

submitted by Areva at the end of 2008 takes into account 4 scenarios depicting the reutilisation of mining waste rocks (true or selective) in the public area, namely, roads, a farm yard, a school playground, a company platform. These scenarios correspond to the most frequently observed cases of reutilisation of waste rocks and do not exceed in the first approach the addition of 1 mSv/year. Recall that within the framework of ″nuclear activities″, the regulatory value fixed by the public health code is 1 mSv/year added to the natural radioactivity.

2.4.2. Waste with enhanced natural radioactivity

Waste with enhanced natural radioactivity are waste generated by the transformation of raw materials naturally rich in radionuclides and which are not used for radioactive properties. This waste originates from various sources and presents significant volumes. This is a long lived waste. Its radioactivity is due to the presence of natural radionuclides : potassium 40, radionuclides of the uranium 238 family, radionuclides of the uranium 235 family, radionuclides of the thorium 232 family.

In June 2009, in application of article 12 of the decree of 16 April 2008 fixing the prescriptions related to the PNGMDR, ASN submitted to the Ministers of Health and the Environment an assessment of the management of waste with enhanced natural radioactivity. To elaborate this assessment, ASN relied on two studies elaborated by the Robin des Bois Association.

Waste with enhanced natural radioactivity is broken down into two categories :

- Very low level and long lived waste, which represents the largest volumes of waste with enhanced natural radioactivity (for example, historical repositories of phosphogypsums and coal ash, foundry sand waste, zirconium-based refractory waste used notably in the glass industry, etc.) ;
- Low level and long lived waste (for example, some waste originating from the processing of monazite, some waste originating from the production of zirconium sponge, some waste originating from the dismantling of industrial facilities already produced or to come, originating, for example, from production plants of phosphoric acid, processing of titanium dioxide, processing of zircon flour, old processing activities of monazite).

Moreover, some urban development work also used in the past backfill of materials originating from conventional industry, but with low radiological activities. This is the case for the harbour zones of La Rochelle whose installations were backfilled with residues originating from historical production activities of rare earths from monazite ore.

Uncertainties still persist on the produced waste volumes, as well as the radiological activity of some waste. In fact, the concerned sectors of activity are very varied and the large number of industrialists make it difficult to draw up an exhaustive inventory, the data not being necessarily available. Moreover, the quality of the available data is very heterogeneous.

Some of the activities which led to the production of waste with enhanced natural radioactivity whose mass activity is the highest have stopped. Only a limited number of companies continue to produce this waste. However, a number of processes lead to the formation of scales which can have a high level of activity (several tens of Bq/g) belonging to the low level waste category.

Waste with enhanced natural radioactivity of a very low level are either eliminated in disposal centres of dangerous, non dangerous or inert waste, or eliminated at the very low level waste disposal centre operated by Andra, or eliminated in an internal dump. In the past, disposals of ash and phosphogypsum waste, which is waste with enhanced natural radioactivity of a very low level, were made up. Each of these disposals represents generally at least several hundreds of thousands of tonnes. Some ash disposals are recovered for a reutilisation of the ash in public works fields. A few disposals were or will be re-engineered (leisure areas, etc.). Only a part of the ash and phosphogypsum disposals is being monitored. However, this monitoring concerns only the chemical parameters and not the radiological parameters.

Waste with enhanced natural radioactivity of a low level is generally stored at the industrialists because no elimination management route is operational today. This storage is done either in buildings or outdoors. For some outdoor storages, measures were taken or will be taken to protect the waste from rainwater. In the past, a few thousand tonnes of waste with enhanced natural radioactivity of a low level were disposed of in dangerous or non-dangerous waste disposal centres.

Work was conducted to verify the acceptability of waste with enhanced natural radioactivity in the disposal centres. It led to the elaboration of the Ministry of Ecology circular of 25 July 2006 and an IRSN methodological guide for the acceptance of waste with a natural radioactivity in classified elimination facilities.

Improvements to be made to the solutions for the management of waste with enhanced natural radioactivity are discussed in section 3.4.2.

2.4.3. Radioactive waste disposed of in conventional disposal centres

Radioactive waste was disposed of in the past in technical burial centres which were closed or re-engineered for the most part. The waste consists of essentially sludge, earth, industrial residues, rubbish and scrap iron originating from some historical activities of the conventional industry and even, in some cases, the civil or military nuclear industry. Generally, two types of disposals are distinguished : dangerous waste disposals, previously designated under the term of class 1 rubbish centres and non dangerous waste disposals designated under the term of class 2 disposals. The ministerial order of 30 December 2002 related to the disposal of dangerous waste and the ministerial order of 9 September 1997 related to the disposal of non dangerous waste prohibit the elimination of radioactive waste in these centres ; this prohibition dates back in practice to the early 1990s. Radioactivity detection procedures at the entry of disposal centres must be implemented to prevent the entry of radioactive waste in these facilities and, if necessary, address them to authorised management routes.

The geographical inventory of radioactive waste published by ANDRA lists 11 rubbish sites which received in the past radioactive waste. For example, let us mention the Vif dump which received fabrication process residues from the Cézus plant, phosphate transformation residues disposed of in the Menneville dump, or also the dumps of Pontailler-sur-Saône and Monteux which received, respectively, the waste originating from the clean-up sludge of the study centre of Valduc and from zirconium oxide fabrication. A dump of Solérieux contains fluorines originating from the Comurhex plant. Since they were closed, these old rubbish burial sites have been subject to monitoring measures imposed on classified facilities (mainly chemical pollution measurements, settling checks, and implementing, if necessary, of ancillary public utility services). For the sites recorded in the ANDRA inventory which received the most radioactivity, more or less complete monitoring measures depending on the site provide for the radiological follow-up of the groundwater (which is the case for the Vif or Monteux dumps).

2.5. Long-term waste management : assessment of the research on new management routes

Current research on new routes for the long-term management of radioactive waste concerns sealed radioactive sources, tritium-bearing waste, low level and long lived (LL-LL) waste, and high or intermediate level and long lived (HL/IL-LL) waste.

Research programmes are common to all the management routes concerning, in particular, the conditioning and the behaviour of the waste, on the one hand, and the modelling and the simulation, on the other hand.

In the field of waste conditioning and waste behaviour, waste producers and Andra set up control and exchange structures to guarantee the consistency of all the R&D programmes. An Act now states that producers are responsible for the characterisation of the packages and studies on the intrinsic behaviour of the packages (creating a knowledge file and an operational model describing the long-term behaviour of this package), while Andra is in charge of interactions between the packages and the surrounding materials. Current programmes are mainly interested in the following waste and package categories :

- waste conditioned via the industrial management of the spent fuel, such as practiced at La Hague ;
- so-called “historical” waste, stored at Marcoule and La Hague during the industrial reprocessing spent fuel before the start-up of the UP3 plant (1990) or the waste from research activities during the same period. A part of this waste is still in a raw form or, in some cases, may necessitate a reconditioning. In conformity with the requirements of the Act of 28 June 2006, this operation should be completed in 2030 ;
- radium-bearing waste, originating mainly from the processing of ores for the chemical industry;
- graphite waste, originating from the dismantling of the graphite moderated, gas cooled natural uranium reactors (R&D driven within a joint structure uniting Andra, CEA and EDF) ;
- waste originating from clean-up operations resulting from the shutdown and waste originating from various deconstruction phases of the facilities ;
- fuels from navy nuclear propulsion[15] and research reactors (studies conducted in CEA – Andra partnership).

For the modelling and simulation programme, the work conducted by Andra with CEA during the years 2006 and 2007 allowed notably the implementation of new functionalities for transport in an unsaturated environment, the coupling of package degradation models with the environment, as well as the mechanics and the extension of the chemistry-transport coupling. Other work enhanced the "Alliances" tool (allowing the analysis and simulation of phenomena to take into account in the studies on the storage and disposal of radioactive waste). Finally, computational capacities and the potential of certain codes were increased, particularly to work on large mesh topologies. In parallel, work conducted within the framework of the PACEN programme is aimed at combining and interconnecting competences in mathematical modelling, numerical analysis and scientific computation, notably to respond to requests on the geological repository.

2.5.1. Waste containing tritium

98% of tritium-bearing waste without outlet produced in France is waste originating from the operation and dismantling of facilities linked to CEA military applications, the rest originating from activities linked to research or from the pharmaceutical and hospital sector classifed under the generic term of ″diffused nuclear sector″. It represents today a little more than 3500 m^3 for an estimated inventory on the order of 5000 TBq. This waste is combined according to its inventory as tritium bearing and more particularly its degassing.
Between 1999 and 2005, CEA[16] engaged actions designed to obtain better knowledge about the inventory of the tritium-bearing waste of other producers and study conditioning processes or

15 Since the option of processing these fuels at the La Hague plant is still being studied, they may not be considered as waste.
16 EDF and AREVA do not have tritium-bearing waste without a management solution.

processing methods to have them accepted in an existing disposal management route. However, considering tritium's high mobility through their media, even in containers made to be the best leak-proof possible and in the concrete structures of the Aube disposal centre, it does not seem possible to accommodate it in surface disposals ; this practice would have as a consequence the tagging of the water table around the disposal by tritium, which is not compatible with the objective of not tagging the environment of LL/ILDC.

Today's operational management routes for the elimination of tritium-bearing waste concern only the least active waste. It can be processed in the CENTRACO facility for liquid waste. For other waste, shipment to the Andra disposal centres is subject to stringent requirements[17].

Future management routes such as the HL/IL-LL or LL-LL disposal centres have been identified. For waste containing significant quantities of practically immobile tritium (graphites, B4C, etc.), the presence of ″included″ tritium does not seem to impose additional requirements.

The main part of the waste currently produced by CEA is processed and/or stored on the Valduc and Marcoule sites. The CEA facilities at Marcoule, whose operation generates tritium-bearing waste, will be shutdown by 2012. The pure tritium-bearing waste originating from the dismantling of these facilities will be evacuated to Valduc for processing (tritium removal) and then storage.

Considering that there is no managmenet route for most of the French tritium-bearing waste, the Act of 28 June 2006 related to the sustainable management of radioactive materials and waste provides for within the framework of the National Plan for the Management of Radioactive Materials and Waste (PNGMDR) : *the development by 2008 of storage solutions for waste containing tritium to allow reducing its radioactivity before its disposal on the surface or at a shallow depth″.* The decree of 16 April 2008, fixing the prescriptions related to the PNGMDR, specifies that :
″The Atomic Energy Commission (CEA) will submit to the ministers of energy and the environment at the latest by 31 December 2008 a study on storage solutions for waste contaminated with tritium already produced and to come and not liable to be disposed of directly in the ANDRA disposal centres. This study will specify the deadline for this waste to be taken care of in the ANDRA disposal centres. CEA will strive, in particular, to take into account the requirements, notably in terms of safety and transport, in order to justify the number of storages by decay necessary for this type of waste. This study will present the safety orientations and specify the storage design, construction and operation provisions which will limit, wherever possible, the migration of tritium into the environment. CEA will propose a timetable to implement the envisioned storage solutions and will submit an initial estimation of their cost. The ministers will call on the Nuclear Safety Authority (ASN) for its opinion.″

CEA submitted within the framework of the application of article 9 of the decree of 16 April 2008 an orientation file for the storage of tritium-bearing waste without a process. The storage project for the tritium-bearing waste without a management route concerns according to the study's data all the solid tritium-bearing waste already produced and to be produced by 2060, the final date of the dismantling of the ITER facilities. Thus, this inventory would reach by 2060 a volume of tritium-bearing waste on the order of 30 000 m^3 for a radiological activity in tritium of approximately 35 000 TBq. The following waste is not concerned by the study : solid and liquid waste liable to be processed in the CENTRACO facility ; waste which can be evacuated in an Andra disposal centre without prior storage ; and waste which can be a priori evacuated without prior storage to future disposal centres of low level and long lived (LL-LL) waste or intermediate or high level and long lived (MHLL) waste.

[17] For the waste received in LL/ILDC at Soulaines, the accommodation specifications limit the quantity of tritium released per day and per mass unit to 2 Bq/g/d and to 1000 Bq/g per waste lot.

From the presented inventory, CEA retained notably six main waste categories without outlet :

- very low level tritium-bearing waste (pure or mixed tritium-bearing waste) ;
- pure tritium-bearing waste practically not degassing ;
- pure tritium-bearing waste degassing[18] ;
- tritium- and uranium-bearing waste ;
- irradiating tritium-bearing waste containing short lived radionuclides ;
- irradiating tritium-bearing waste containing long lived radionuclides.

Each tritium-bearing waste family is associated with a storage concept of a sufficiently long duration to allow the decay of the packages activity and to take care of them in an elimination management route. The project retains the following principles for the design of storages :

- the reception and unloading of the shipping casks and the full packages : the waste is sorted and the packages are made by the waste producer. Tritium removal operations by oven drying, heating or melting for the most active waste to reduce the tritium inventory or tritium degassing are performed at the producers ;
- the storage of packages for a fifty-year period ;
- the design of modular structures adapted to each waste category ;
- the environmental monitoring of the facility and the entire site ;
- the control of packages and canisters ;
- the construction of storages in the proximity of the main production sites.

The general characteristics of such storages are given in the table below.

[18] A tritium-bearing waste is considered to be practically not degassing if the unit measurement of tritium degassing from each package is less than 1 GBq/year/package.

General characteristics of the storages envisioned by CEA for the disposal of tritium-bearing waste

	Regulatory status	Structure	Storage principle	Ventilation	Capacity	Envisioned number		Annual discharges in tritium	Tritium impact/scenario			Final outlet envisioned
									Internal fire	Earth-quake	Handling (worker dose)	
VLL waste	Authorised ICPE	Module in metal formwork	3-level stacking of packages	Natural ventilation	1 000 packages (1 PBq)	3	No dimensioning for earthquake	< 1 TBq	< 5 µSv at 500 m	< 2 µSv at 500 m	< 40 µSv	VLL type
Pure tritium-bearing waste hardly degassing	INB	Module in metal formwork	5-level stacking of pallets (4 drums)	Natural ventilation	15 000 drums (10 PBq)	3 (Valduc)	No dimensioning for earthquake	20 TBq	< 3 µSv at 500 m	< 15 µSv at 500 m	< 40 µSv	LL/IL type
Pure tritium-bearing waste degassing	INB	Module in metal formwork	5-level stacking of pallets (4 drums)	Ventilation by extraction with exhaust shaft	7 000 drums (70 PBq)	2 (1 Valduc 1 ITER)	Dimensioned for earthquake	140 TBq	30 µSv at 500 m	20 µSv at 500 m	0.8 mSv	LL/IL type
Tritium- and uranium-bearing waste	INB	Confining concrete shutters	Stacking	Ventilation by extraction with exhaust shaft	1 000 drums (10 PBq)	1 (Valduc)	Dimensioned for earthquake	20 TBq	30 µSv at 500 m	1 µSv at 500 m	0.8 mSv	LL/IL type
Irradiating short lived waste	INB	Concrete structure (radiological protection)	Stacking (remote handling)	Ventilation by blowing / extraction with exhaust shaft	Equivalent 26 900 drums of 113 l (12 PBq)	3 (1Marcoule 2 ITER)	Dimensioned for earthquake	100 TBq	Exclu-ded (concrete pack-ages)	20 µSv at 500 m	Excluded (remote handling)	LL/IL type
Irradiating long lived waste	INB	Ventilated shafts	Shaft (7 packages per shaft)	Nuclear ventilation (shaft) w/ tritium strip-ping unit	1 232 packages	3 (ITER)	Dimensioning for earthquake of bridges and shafts	35 TBq		70 µSv at 500 m		Deep geological repository

The construction timetables of the various modules are spread out over time. The first scheduled constructions would concern the pure tritium-bearing waste by 2012 for the Valduc centre, which regularly pursues the construction of modules for its own needs and the last would concern the irradiating long lived waste originating from the dismantling of ITER (2050). The timetable for implementing these storages is consistent with the tritium-bearing waste production scenarios presented by CEA.

Cost estimations are indicated in the orientation file submitted by CEA. Costs vary according to the particularities related to the waste and the presence in some cases of some highly irradiating gamma emitters. They vary from a few million euros for the construction of a VLL tritium-bearing waste storage module to forty million euros for the construction of an irradiating long lived waste storage module.

2.5.2. Disused sealed radioactive sources

For the management of disused sealed radioactive sources, a first step was made with the creation of the Public Interest Group related to sealed high level radioactive sources (called "PIG HL Sources"), which will allow in the future recovering, conditioning, and storing sealed high level radioactive sources (notably cesium 137 and cobalt 60) fabricated and distributed in France by CEA until 1984 and by Cis-Bio until 2006, as well as orphan sources of the same kind.

In compliance with the decree of 16 April 2008 fixing the prescriptions related to the PNGMDR, Andra submitted in December 2008 to the minister of energy and the environment a study of the solutions to allow disposing of disused sealed radioactive sources in the existing centres or in centres to be constructed. It covers all the disused sealed radioactive sources[19] such as defined by the public health code, that is, sources aged more than 10 years, except for special usage conditions and ″whose structure or conditioning prevents under normal utilisation any dispersion of radioactive materials in the ambient environment″.

Disused sealed radioactive sources are very diversified : radionuclides, activities, forms, etc. In order to take into account this diversity, Andra drew up an inventory of disused sealed radioactive sources in France in connection with their main holders (including the French manufacturers CEA, CIS Bio International/IBA Group and Cerca/ AREVA Group). IRSN provided its expertise to create this inventory.

According to Andra estimates, the companies of the French Group of Fire Safety Electronic Industries (GESI) hold in number approximately 65% of disused sealed radioactive sources, National Defence nearly 22% (essentially electronic tubes) and the industrial and medical sources mainly held by CEA 10% and CIS-BIO 0.3%. Andra, whose mission is notably to collect ″unclaimed″ disused sealed radioactive sources, holds approximately 1.3 %. The verified consistency of the national inventory of IRSN sealed radioactive sources currently in use with the aforementioned inventory compiled by Andra listing the disused sealed radioactive sources lets one think that the various types of sources were appropriately identified, allowing them to be oriented to the various possible disposal management routes. However, this inventory of the disused sealed radioactive sources to be disposed of should be periodically re-evaluated according to the sales made, returns to manufacturers, and new estimates of the quantities held by the various agencies and organisations.

The reuse of some disused sealed radioactive sources is another management possibility compared to that of disposal. This is particularly the case for gaseous sources whose gas may be recovered, for the sources of radionuclides which are costly to fabricate and possibly for those allowing the reuse of the properties of some contained radionuclides whose decay is slow, notably Am 241 or Cs 137.

The Andra study is based on a disposal of disused sealed radioactive sources in existing management routes or in management routes to come designed for radioactive waste (surface disposal centres for very low level waste – VLLDC – and low or intermediate level and short lived waste – LL/ILDC, future disposal centres for LL-LL and HL/IL-LL waste). In 2001, Andra established the acceptability limits of

[19] To be prudent, the study was extended to sources which would not strictly correspond to this definition (such as radioactive lightning rod sources).

sealed radioactive source packages at LL/ILDC with, on the one hand, an activity criterion for the packages and structures called the ″mass activity limit″ (MAL) and, on the other hand, an activity criterion per radionuclide for each source called the ″source activity limit″ (SAL). This SAL is estimated in such a way as to limit the exposure notably in the case of a package fall scenario during the time of an operation or human intrusion with the recovery of a disused sealed radioactive source beyond the monitoring time. Since 2007, some disused sealed radioactive sources can already be disposed of at LL/ILDC. They are disused sealed short lived radioactive sources with a half-life less than or equal to the half-life of cesium 137, that is, 30 years, with activities below certain thresholds depending on the concerned radionuclide. These thresholds or activity limits result from an evaluation of the compatibility with the safety of the disposal on the same bases as other waste, but also taking into account the sources specificity.

The specificity of the sealed radioactive sources is their concentrated activity and their potentially active nature. In the case of human intrusion after a disposal is no longer monitored and forgotten, this attractiveness may lead to a recovery of disused sealed radioactive sources by individuals who are not aware of the danger. If the impact which would result from this recovery is deemed excessive, the disused sealed radioactive source is considered to be unacceptable in the disposal.

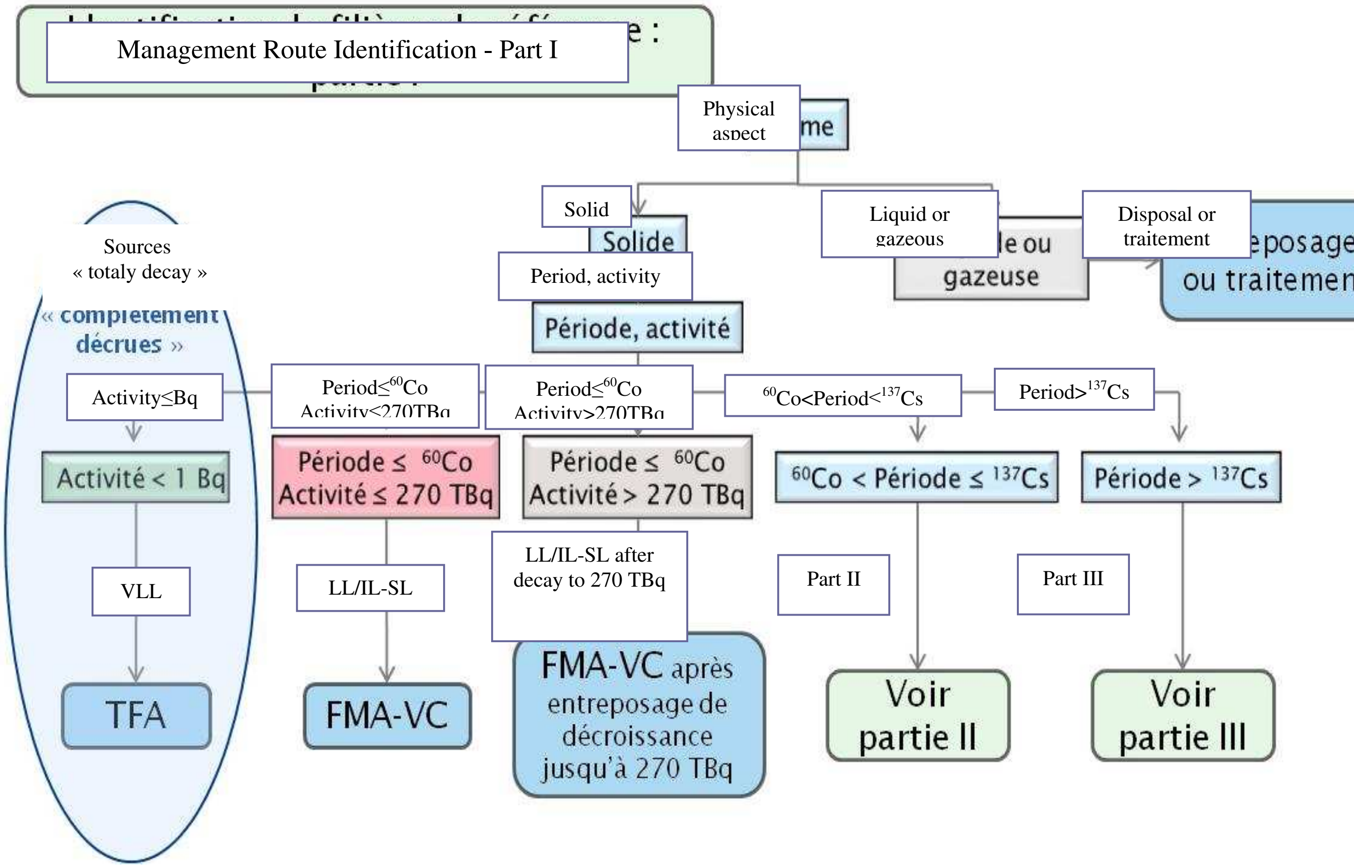
Except for disused sealed liquid or gaseous radioactive sources, which cannot be disposed of in this form, the disposal management routes proposed by Andra would allow taking care of disused sealed radioactive sources in the state they are without any physical denaturation. Approximately 83% of the listed two million disused sealed radioactive sources would thus be disposed of in shallow depth disposal, 15% in surface disposal and 2% in the deep geological repository.

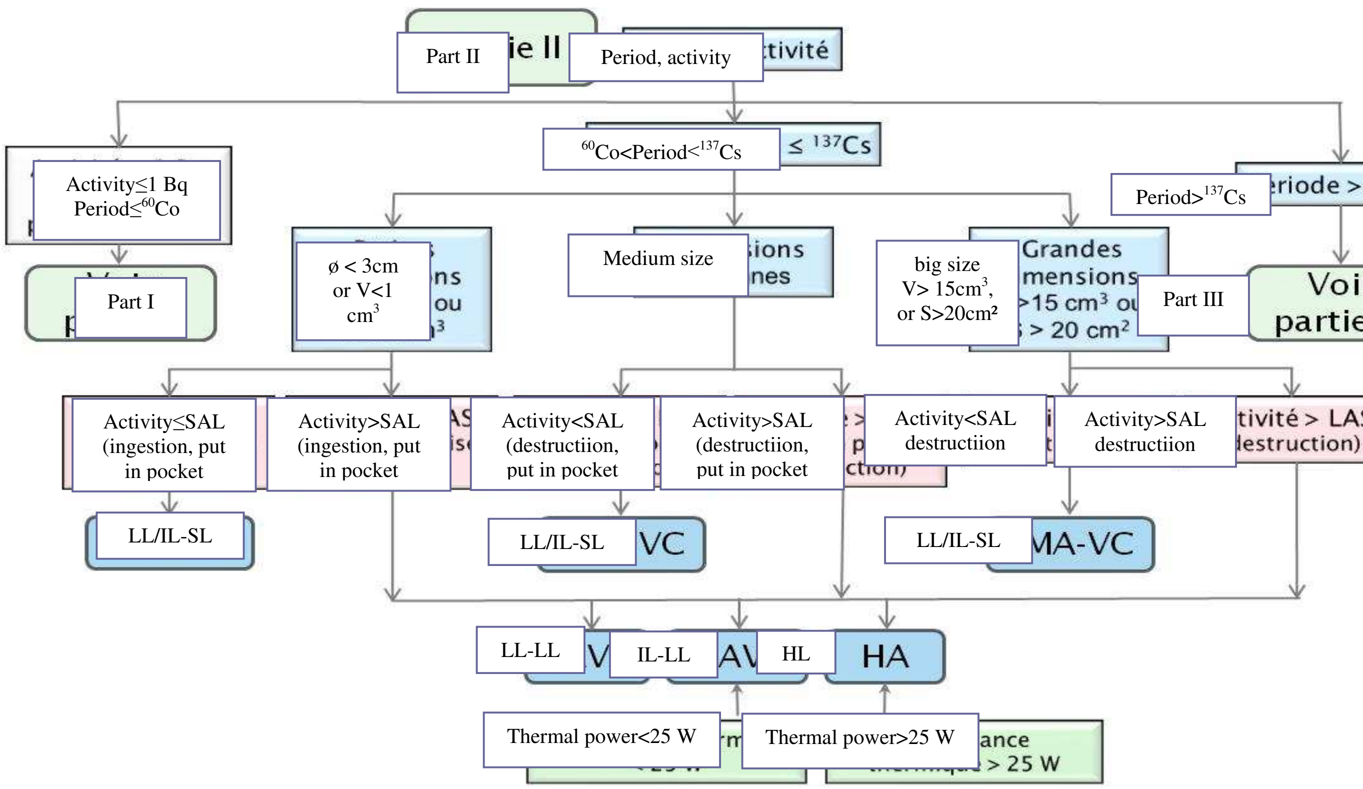
For sources considered unacceptable at LL/ILDC, Andra examined disposal possibilities in the LL-LL waste management route by making a distinction between two options for study : disposal under a recast covering (SCR) and disposal under an intact covering (SCI).

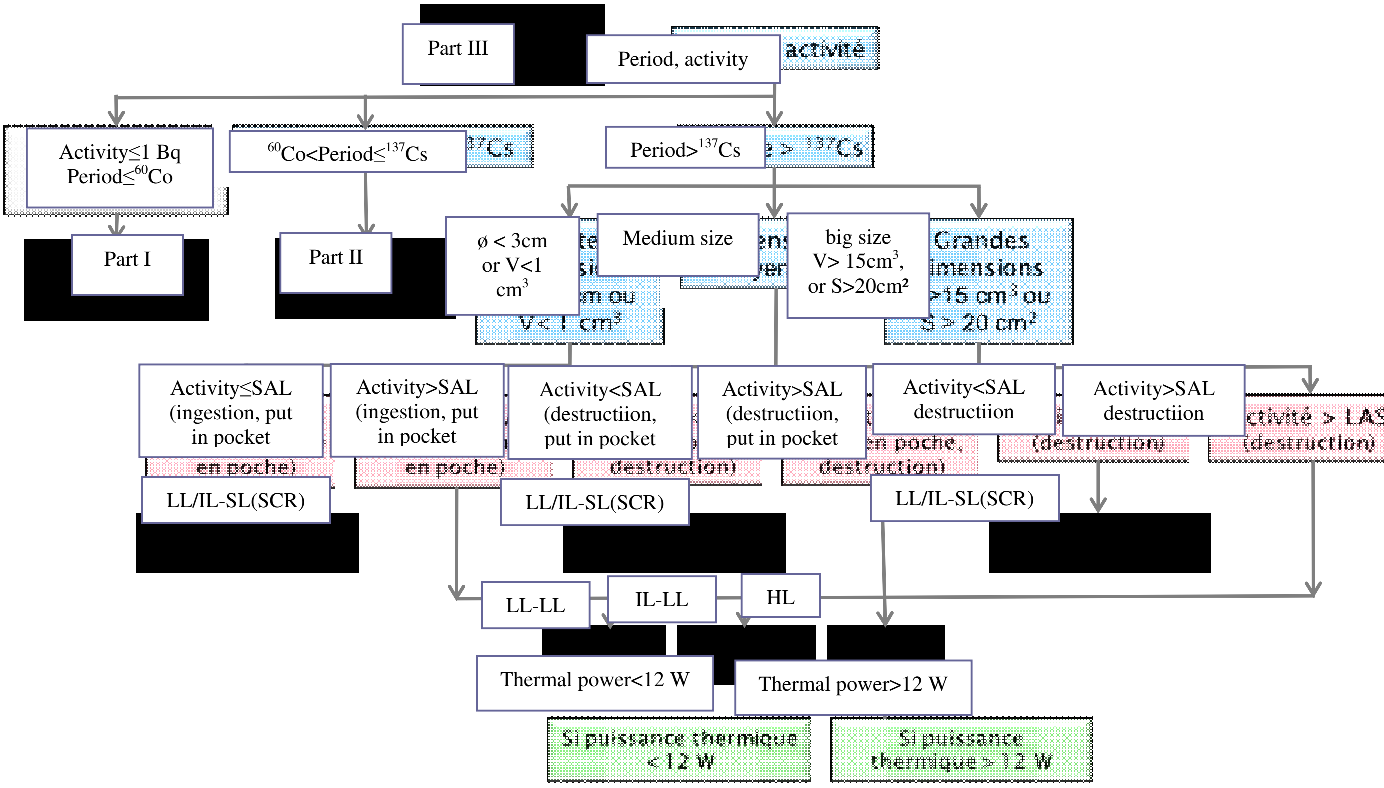
The study extended to shallow depth disposal the application of acceptance limits resulting from sealed radioactive sources recovery scenarios. It takes qualitatively into account the reduction of the probability of ″deep depth recovery″ scenarios ; from this viewpoint, it differentiates the two recast and intact covering concepts.

Disused sealed radioactive sources unacceptable for surface or shallow depth disposal were assigned to the deep geological repository as follows : the least exothermic disused sources with the IL-LL waste and the most exothermic disused sources with the HL waste.

The identification method of disposal management routes is summarised by the decision-making tree presented hereafter, which applies the followiing successive criteria to each disused sealed radioactive source : the radioactive substance’s state : solid, liquid or gas ; the half-life : short (that is, less than cobalt 60), medium (less than cesium 137), or long ; the disposal package’s activity ; and the compatibility with other disposal parameters, essentially thermal power and the chemical nature.


Management Route Identification - Part I
Physical aspect
Solid
Liquid or gazeous
Disposal or traitement
Period, activity
Sources « totaly decay »
Activity≤Bq
Period≤60Co Activity<270TBq
Period≤60Co Activity>270TBq
60Co<Period<137Cs
Period>137Cs
VLL
LL/IL-SL
LL/IL-SL after decay to 270 TBq
Part II
Part III
TFA
FMA-VC
FMA-VC après entreposage de décroissance jusqu'à 270 TBq
Voir partie II
Voir partie III


Part II
Period, activity
60Co<Period<137Cs
Activity≤1 Bq Period≤60Co
Period>137Cs
Part I
ø < 3cm or V<1 cm3
Medium size
big size V> 15cm3, or S>20cm²
Part III
Activity≤SAL (ingestion, put in pocket
Activity>SAL (ingestion, put in pocket
Activity<SAL (destructiion, put in pocket
Activity>SAL (destructiion, put in pocket
Activity<SAL destruction
Activity>SAL destructiion
LL/IL-SL
LL/IL-SL
LL/IL-SL
LL-LL
IL-LL
HL
HA
Thermal power<25 W
Thermal power>25 W


Part III
Period, activity
Activity≤1 Bq Period≤60Co
60Co<Period≤137Cs
Period>137Cs
Part I
Part II
ø < 3cm or V<1 cm3
Medium size
big size V> 15cm3, or S>20cm²
Grandes dimensions >15 cm3 ou S > 20 cm2
Activity≤SAL (ingestion, put in pocket
Activity>SAL (ingestion, put in pocket
Activity<SAL (destructiion, put in pocket
Activity>SAL (destructiion, put in pocket
Activity<SAL destructiion
Activity>SAL destructiion
LL/IL-SL(SCR)
LL/IL-SL(SCR)
LL/IL-SL(SCR)
LL-LL
IL-LL
HL
Thermal power<12 W
Thermal power>12 W
Si puissance thermique < 12 W
Si puissance thermique > 12 W

An arbitrary threshold of 1 Bq per source was used within the framework of the study to identify the disused sealed radioactive sources of very low activity. This threshold may be respected by sources with a very short half-life which have sufficiently decayed (typically for a half-life less than approximately 300 days, such as polonium 210, cobalt 57 and germanium 68) ; it may also concern a few sources with a longer half-life, but with an initial very low level. Andra proposes to dispose of these disused sealed radioactive sources at VLLDC. Moreover, Andra recalls that sealed radioactive sources containing a radionuclide with a half-life less than 100 days can be managed by radioactive decay followed by a declassification (into conventional waste), in conformity with PNGMDR. Andra mentions the opportunity to dispose of these declassified disused sealed radioactive sources at VLLDC in order to circumvent possible problems linked to the ″dispersion″ of decayed sources whose ionising radiation indicator symbol would not have been erased. This approach prevents the risk of returning radioactive sources unintentionally into the public field.

For safety, all disused sealed radioactive sources with Co^{60} and disused sealed radioactive sources whose half-life is between that of Co^{60} and that of Cs^{137} and whose activity is less than the SAL may be disposed of at LL/ILDC. For disused sealed radioactive sources with a half-life less than or equal to that of Co^{60}, the operation safety of LL/ILDC imposes that the activity of each package be less than 270 TBq, which necessitates for some of these sources a storage by decay (up to fifteen years).

The disused sealed radioactive sources intended for the shallow depth disposal are :

- most of the sources containing long half-life radionuclides ;
- sources of short half-life radionuclides, but with a descendant of a long physical or neutron half-life : Pa^{233}, Cm^{244} and Cf^{252}.

In addition, some disused sealed radioactive sources composed of radionuclides with a short or medium half-life unacceptable at LL/ILDC may be disposed of at a shallow depth if their activity remains compatible with the intrusion scenarios to be taken into account.

The disused sources of smoke detectors are intended for shallow depth disposal. The disused sources (or the heads) of lightning rods with Am^{241} can be disposed of at a shallow depth. This would also be the case for those with Ra^{226} and mixed if the risk of recovery would prove to be a non dimensioning factor. The disposal of radium-bearing needles and other objects for medical use is proposed for the deep geological repository.

The most active spent sources containing Pu^{239}, Pu^{240}, Pu^{242}, Th^{232}, neutron-rich elements, the source rods of EDF nuclear reactors and source blocks are to be disposed of in the deep geological repository. This is also true for some very active sources containing Sr^{90} or Cs^{137}.

For the disposal, the main processes to be implemented are a dismounting of the devices containing the sources and an appropriate conditioning for each disposal process (most of the disused sealed radioactive sources are not conditioned today). Special attention is to be paid to the reduction of the volumes to be disposed of, the transport requirements and the storage conditions (available capacities in volume and activity, dose rates). Additional processes can optimise the management of some sources. Thus, for lightning rod heads containing Ra^{226}, the currently applied compacting process prior to storage may allow a shallow depth disposal if the risk of recovery is very unlikely.

A global vision of the management of various disused sealed radioactive sources, their recovery or their collection up to their disposal will allow anticipating better the requirements of each management phase and their consequences on the disposal. Proposals are made in chapter 3.5.1. of this report.

2.5.3. Low level and long lived (LL-LL) waste

Overview of the disposal centre project for LL-LL waste

The opening of a disposal centre for low level and long lived (LL-LL) radioactive waste is one of the objectives fixed by the Act of 28 June 2006 related to the sustainable management of radioactive materials and waste.

This waste consists of :

- ″graphite″ waste, originating from the operation and the future dismantling of EDF nuclear reactors of the ″graphite moderated, gas cooled natural uranium″ type (reactors of Bugey, Chinon and Saint-Laurent des Eaux) and CEA experimental reactors (Saclay, Marcoule) ;
- ″radium-bearing″ waste, originating essentially from the processing of ores containing rare earths, used to manufacture electronic components, catalytic exhaust pipes in the automotive industry, and in fine metallurgy. The residues preserve and even concentrate the natural radioactivity of the ores. They are currently stored on industrial sites : Rhodia plant of La Rochelle, CEA centre of Cadarache, Cézus plant of the AREVA Group at Jarrie in the Isère department. Radium-bearing waste also originates from historical activities, such as the fine-tuning of uranium ore concentration processes (CEA site of Itteville in the Essonne department), as well as the rehabilitation of industrial sites contaminated by radium (earth originating from the decontamination of the Bayard watch-making plant, for example).
- other types of waste, for which the possibility of taking care of them in the future LL-LL disposal must be confirmed ; for example : some old bituminised waste stored on the CEA site of Marcoule, some process waste originating from dismantling, some disused sealed radioactive sources (fire detector sources, radioactive lightning rod sources collected by Andra).

The waste inventory is estimated at this stage between 50 000 and 100 000 tonnes of raw waste, that is, a volume of conditioned waste on the order of 200 000 m3. By comparison, the Aube radioactive waste disposal centres have a capacity of 650 000 m3 (VLL) and 1 000 000 m3 (LL/IL).

This waste must be handled by a specific management adapted to its long lifetime, which prevents it from being disposed of in the Andra surface disposal centres located in the Aube department. Its slow radioactivity does not justify, however, disposing of it at a deep depth (on the order of 500 metres for high or intermediate level and long lived waste).

The privileged technical option is a shallow depth disposal. Andra is studying, in particular, a subsurface disposal in a slightly permeable geological layer (essentially clayey or marly soil) sufficiently thick (at least 50 metres). Two disposal types are under study : the disposal under a recast covering (SCR) corresponds to an open-pit excavation used to access the disposal level and backfilled once the waste is disposed of ; the disposal under intact covering (SCI) consists of digging into the subsoil and making longitudinal access drifts which will be backfilled once the waste is disposed of in them.

Pending the selection of a site, these various options were studied based on realistic characteristics of generic sites derived from bibliographic studies. The option of a disposal under intact covering is privileged for the graphite waste. In fact, thanks to the greater depth of the clay, the flow of radionuclides liable to rise to the surface can be better delayed and attenuated. For radium-bearing waste, the need for a solutes transport barrier is less of a requirement because this waste is characterised by a lower radiological activity. Also, the study of both design options – recast or intact covering – is being pursued for radium-bearing waste.

Launching the search for a site

The Act of 28 June 2006 sets the milestone of 2013 for the placing in operation of a disposal centre for graphite waste and radium-bearing waste. However, due to the project's technical and organisational constraints (notably to search for a site), the analyses of Andra, CNE and the High Commissioner for Atomic Energy showed that this timetable was no longer realistic. At the end of 2007, on the request of its trustees, Andra proposed a new timetable with the placing of the disposal in operation now scheduled for 2019. The inventory of the disposal, the safety objectives, as well as a detailed examination of the interactions with the EDF dismantling programme, become effective during the first half of 2008.

On 2 June 2008, the Minister of State entrusted to Andra's CEO the mission of launching the request for candidates with the local communities to pick a LL-LL waste disposal site and validated the objective of the disposal going into operation in 2019. The Minister of State insisted on the top ranking objective - in terms of nuclear safety - of radiological protection and protection of the environment. He also focused on the necessity of an in-depth concertation with the country's communities and the concerned local populations to allow a dialogue of quality on the impact of such a project in environmental and socio-economic terms.

Andra thus contacted 3115 communes located in the cantons whose geology was potentially favourable for the installation of the disposal centre in order to present the project to them. These communes had until the end of October 2008 to express their interest. Subsequent to this request for candidates, Andra received forty favourable decisions from municipal councils.

At the end of 2008, Andra submitted two studies to the Government : a study on the search for an LL-LL waste disposal site and a study on the possibility of disposing of other types of LL-LL waste with graphite and radium-bearing waste.

Summary of the Andra study on the possibility of disposing of other LL-LL waste with graphite and radium-bearing waste

Andra submitted at the end of 2008 to the Government another study on the possibility of disposing of other LL-LL waste with graphite and radium-bearing waste.

Disused sealed radioactive sources and objects containing radium, thorium and uranium were especially identified as capable of being taken care of ; the volume to be disposed of remains small compared to the graphite and radium-bearing waste. The study also identified other low level waste, in particular, bituminised sludge drums : less active, unacceptable for surface disposal, and representing a much more substantial volume (on the order of 35 000 cubic metres after being conditioned) ; studies must be pursued for this last type of waste.

In addition, it will be possible to condition and dispose of all of the waste without having to separate the waste, the objects and radioactive ore samples collected from the ″diffused nuclear sector″ waste.

Other research on the knowledge and conditioning of LL-LL waste

Studies on the knowledge and behaviour of LL-LL waste aim at understanding, on the one hand, the intrinsic behaviour of the waste package (producer's responsibility) and, on the other hand, the waste package's behaviour in a disposal (Andra's responsibility).

In the case of graphite waste, the programmes are focused on the two most important radionuclides with respect to the long-term radiological impact : chlorine 36 and carbon 14. For chlorine 36, the objective is to know its origin, its chemical state and its location in order to quantify its release in the disposal. For carbon 14, the objective of studies is to verify that it will be released in a non-gaseous inorganic form liable to be strongly trapped by cement materials.

A part of the work directed on the topic to learn more about graphite waste is mutualised at the European scale within the framework of the European Carbowaste Project (VIIth PCRD). Under this programme, alternative graphite management routes by thermal processing will be explored, notably for the waste associated with 4th generation reactors.

Studies on ion exchange resins, which will be used to filter the water when some UNGG reactors are dismantled underwater, are being conducted by EDF in order to know their behaviour in a disposal (release of hydrogen by radiolysis and complexing species).

For radium-bearing waste, studies are focused on the speciation of radionuclides according to disposal conditions by integrating insolubilisation processes implemented by the producers. The effects of complexing species and salts from this waste on the transfer of radionuclides will also be evaluated.

Site options for in-depth investigations to select the disposal

Before pursuing the site selection initiative, the Government consulted the Nuclear Safety Authority (ASN) and the National Evaluation Committee (CNE) concerning the analysis methodology retained by Andra. ASN, which analysed this methodology with respect to the general safety orientation memo covering the search for a site for the disposal of LL-LL waste that it published in June 2008, indicated notably that ″at the actual stage of the analysis, there are no stringently opposing elements, from a geological viewpoint, to not pursue investigations in order to install a disposal centre for low level and long lived waste on one of the sites classified by Andra in a 'very interesting' category from a geological viewpoint″, and that ″the ability of these sites to accommodate a disposal facility may only be confirmed based on the results of in-depth investigations″. CNE came in turn to the following conclusion : ″The decision to select sites which will be covered by an in-depth study is scheduled to take place shortly and the recognition of the rock's essential characteristics will only then follow. After this recognition phase, the quality of the envisioned sites may be evaluated. As a result, despite the the quality of the work performed to date by Andra, a risk persists that none of the selected sites may prove to have the required properties.″

On 24 June 2009, Andra announced the Government's decision to conduct in-depth investigations on two communes, Auxon and Pars-lès-Chavanges, in the Aube department and to verify the feasibility of installing a shallow depth disposal centre for the LL-LL waste. However, the municipal councils of Auxon and Pars-lès-Chavanges decided to withdraw from the project, respectively, on 4 July and 11 August.

The Government and Andra recorded these decisions. The project's next phases are detailed in section 3.5.3.

2.5.4. High or intermediate level and long lived (HL/IL-LL) : separation / transmutation, reversible geological disposal, storage

In conformity with the Act of 28 June 2006, the research conducted on the management of high or intermediate level and long lived waste are conducted in three additional orientations : the separation and radioactive transmutation of long lived elements ; the reversible disposal of ultimate waste in a deep geological layer ; the storage. Additional studies are also underway, notably on the conditioning of the waste.

A few scientific concepts about the research on HL/IL-LL waste

Transmutation designates the transformation following a nuclear reaction from one element into another element. It can take place in a nuclear reactor or in a particle accelerator. It is a studied pathway to eliminate some radioelements contained in the radioactive waste : the objective is to decrease the harmfulness or render it easier to manage high level or long lived radioelements by transforming them into radioelements of a shorter lifetime. To this end, the various radioelements have to be separated before they are submitted to specific neutron fluxes ; the entire process is thus called "separation-transmutation".

Fission products are *residual fragments of heavy nuclei* which have undergone a nuclear fission reaction (or their descendants by radioactive disintegration). Minor actinides correspond to *heavy nuclei produced in a minority*, such as neptunium and americium. High level (HL) waste contains both fission products and minor actinides. At the actual stage of the research, it has been confirmed that separation-transmutation would only concern minor actinides.

Overview of HL/IL-LL waste

HL/IL-LL waste originates from the electronuclear industry, nuclear research and defence activities ; it results notably from the processing of irradiated fuels. After having been irradiated for 3 to 4 years in a nuclear reactor, the fuel contains :

- 96% of major actinides (uranium and plutonium), whose energy potential is still important. They may be reused by recycling ;
- 4% of the elements resulting from the production of energy : the fission products originating from the fission of uranium 235 and uranium 238 and plutonium and the minor actinides (neptunium, americium, curium, etc.).

During the spent fuel reprocessing operation, four types of waste are produced ; the first two originate directly from the spent fuels and are conditioned :

- HL waste (fission products and minor actinides) is conditioned in the form of vitrified standard waste packages. The intense radioactivity of the packages is evidenced by the emission of a thermal power of approximately one to two kilowatts per package when they are being produced. Then it decreases with the radioactivity and is no more than 100 to 200 Watts after a hundred years. Under the actual utilisation conditions of the fuels in the reactors and the elaboration of glass packages, 850 tonnes of spent fuels generate approximately 500 CSD-V glass packages ;
- spent fuel assemblies' cladding waste (intermediate level and long lived waste) : the activation products are found in the cladding and fuel assemblies cladding materials ; their radioactivity, significantly lower than that of the other contributors, must be taken into account due to the long half-life of some radionuclides. Today this waste is conditioned in standard packages of compacted waste. 850 tonnes of processed spent fuels generate based on feedback less than 510 CSD-C packages ;
- technological waste and process waste (intermediate level and long lived waste) : this waste is solid operation or maintenance waste (spent materials, gloves, filters, resins, tank bottom sludge) which is conditioned in cemented packages;
- waste originating from the processing of radioactive effluents (intermediate level and long lived waste) : most of this waste comes today in the form of bituminised waste packages.

In addition to the waste originating from spent fuel reprocessing operations, some cladding activated by neutron fluxes present in the nuclear reactors lead to small quantities of IL-LL waste, for example, control rod clusters or claddings recovered after dismantling. Moreover, CEA research facilities and the national defence programme also produce IL-LL waste.
IL-LL waste, which contains less short-lived radionuclides than HL waste, emits little heat, but requires a long isolation period due to its content in long lived radioactive elements.

Separation and transmutation of minor actinides

Research on the separation and transmutation aims at reducing the dangers and nuisances associated with the presence of long-lived radionuclides in the ultimate waste to be disposed of in the deep geological layer : essentially, reduction of the long-term radiotoxic inventory (1000 years and beyond) and the medium-term thermal load (100 years to 1000 years), which is a dimensioning element of the deep geological repository. Based on this, separation/transmutation is complementary to the deep geological repository (and not an alternative to disposal) ; the purpose of the research in this field is to determine whether it can be an orientation toward progress.

The programme only deals with the transmutation of minor actinides, excluding long lived activation or fission products present in the waste originating from reprocessing spent fuels. Minor actinides due to their very low mobility under the conditions of the studied deep geological repository contribute only slightly to the long-term impact. In fact, the results presented by Andra in its Dossier 2005 show that the only real contributors to the radiological impact at the surface are iodine, chlorine and selenium, their incidence on the dose calculated at the outlet remaining low. On the other hand, minor actinides are the essential contributors to the thermal power of the waste over a century and, based on this, constitute the main "target" of the research programme.

The transmutation methods under study for the minor actinides concern their recycling in the homogeneous mode (in diffusion in the fuels of the 4th generation reactors) or in the heterogeneous mode (in coverings or in dedicated targets) in the 4th generation reactors or in accelerator driven systems (ADS).

The purpose of the studies underway is to evaluate the industrial perspectives of the transmutation of the minor actinides and to devise a research strategy for after 2012, notably through scenarios of technico-economic studies on the entire fuel cycle : what is the contribution of transmutation versus the transmuted nuclei ? which actinides should be recycled ? under what forms of fuels or coverings ? what are the implications on the fabrication of fuels, their handling (loading and unloading), their transport and their reprocessing, and the impact on the geological repository, etc.

The implementation of such a technology can only be conceived for a remote date : it requires the existence of a new processing plant replacing the present La Hague plant and the existence of a number of 4th generation fast neutron reactors in the French installed base. However, even though these dates are still far away, we must prepare for them now because the qualification of fuels with minor actinides necessitates long R&D actions involving irradiation experiments. The industrialisation of processing solutions whose feasibility was confirmed at the laboratory level for some of them is also a long and exacting task. In addition, this work is indispensable for nurturing reflections on the design of the reactors and the plants of the cycle of the future. In consistency with these medium- and long-term objectives, the studies and research to be conducted until 2012 in application of the Act of 28 June 2006 are reviewed and specified in section 3.5.4.

The assessment of the research conducted up to the pilot scale allowed confirming the feasibility of the main separation options. Regarding transmutation, the utilisation of fast spectrum reactors is the only imaginable solution, but the technico-economic performances of the various scenarios still have to be enhanced as a function of the advancement of the design studies (reactor and facilities of the fuel cycle). Once again we stress that it is now confirmed that transmutation will not concern the fission products, even long lived products.

Reversible disposal in a deep geological layer

The studies and research to be conducted over the period 2007-2015 to satisfy the objectives set by the Act in the field of reversible disposal in a deep geological layer were defined in a Development Plan of the project. This Plan was presented in 2007 to the Parliamentary Office for Evaluation of Scientific and Technological Options (OPECST), the National Evaluation Committe (CNE), the Permanent Expert Group on Waste of the Nuclear Safety Authority (ASN) and the Local Committee on Information and Follow-up (CLIS) set up around the Meuse / Haute-Marne underground research laboratory. A summary of this document was also disseminated to the general public. The set-up phase of the HLLL project HAVL was completed in 2007 with the finalisation of the thematic programmes, the project's detailed planning, the set-up of the contractual framework and the kick-off of the studies.

An exploration campaign was conducted in 2007-2008 in the transposition zone located around the Meuse / Haute-Marne underground research laboratory (located in the commune of Bure), a zone in which the results of the research conducted in the laboratory can be transposed. The acquired data reinforce and clarify the geological model of the studied sector and confirm the limits and characteristics of the transposition zone such as they are described in the Dossier 2005. The physico-chemical characteristics of the Callovo-Oxfordian argilite formation do not allow at this stage drawing any discriminating criteria to define a perimeter for the Zone of Interest for Depth Exploration (ZIRA). On the other hand, some geometric characteristics (thickness, depth, hydraulic gradient) constitute objective choice elements. Even though the safety parameters will always remain top priority, the criteria linked to France's land development and the local insertion to take into account in choosing the ZIRA and the associated surface installation scenarios were consolidated with the local players in 2009.

Thus, Andra communicated at the end of October 2009 to the Ministers of Energy, Research and the Environment its proposal for the Zone of Interest for Depth Exploration (cf. Figure 7) and surface installation scenarios compatible with this zone of interest to be studied for the public debate scheduled for 2013.

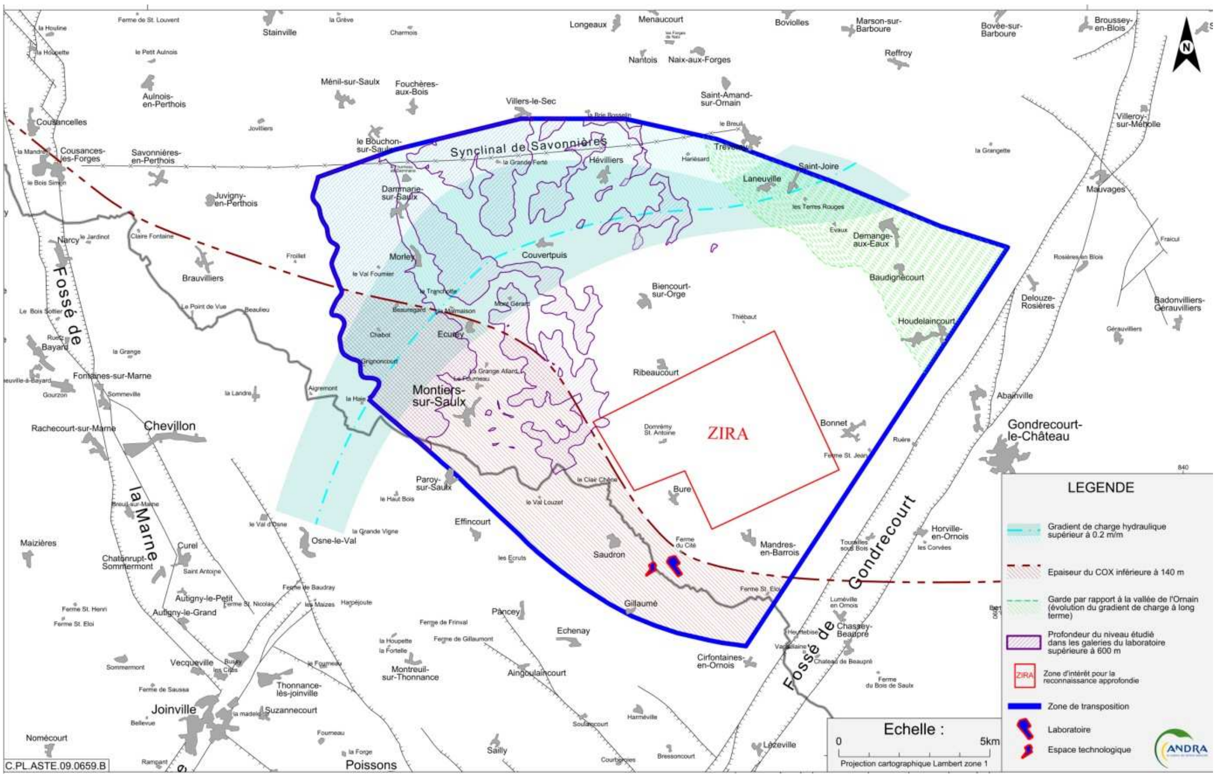


Figure 1. Zone of Interest for Depth Exploration (ZIRA) proposed by Andra
(zone in which in-depth research will be conducted for the installation of the underground facilities of the geological repository)

To dimension the disposal centre project, a ″dimensioning inventory model″ (MID) has been created. This model identifies the production scenarios, lists the various waste packages to be taken care of and describes the main characteristics (radionuclide content, dose rate, release of heat, etc.). The MID adds margins to the waste producers' forecasts to take into account the uncertainties on the electronuclear production and waste management scenarios, the package characteristics, and their inventory. It also takes into account the uncertainties on the acceptability of some waste in the current or future surface or shallow depth disposals. The MID thus defines prudent input data for the dimensioning of the future deep geological repository.

The first version of the MID allowed elaborating the project on the feasibility of the disposal centre submitted in 2005. A new version was elaborated in 2009 to prepare the next scheduled events provided for by the Act (public debate on the disposal centre project and then submission of a creation authorisation application file). The MID version 2009 takes into account in a better way the dismantling waste of the current facilities and the waste originating from the last fuels of the installed electronuclear base (before the decommissioning of the reactors). For future waste, uncertainties exist on the operating duration of the current installed electronuclear base : some reactors could see their operating duration extend up to 50 or even 60 years, but today no statement in this respect can be made. These uncertainties are managed by dimensioning margins.

To make up the authorization application file to create the deep geological repository, two scenarios are considered :

- a basic ″all processing″ scenario, except for spent fuels originating from research and nuclear propulsion, for which a direct disposal hypothesis is examined. This scenario is based on a capacity to recycle the separated materials beyond the engaged installed base. It adopts the hypothesis of a deferred processing of spent MOX fuels, consistent with the future launching of 4th generation reactors.
- a dimensioning scenario, adding an additional dimensioning margin to those considered in the aforementioned basic scenario, conventionally set at +50 % for some waste categories ;

this margin allows covering a possible extension of the operating duration of the engaged installed base and the incidentals on the deconstruction operations.

This dimensioning scenario proposed by Andra at the end of 2009 thus provides for :

i) approximately 12 000 m3 of ″primary packages″ of HL waste, which would correspond to approximately 25 000 m3 after conditioning for the disposal, broken down into :
- vitrified ″C0″ waste (characterised by a moderate thermal release) ;
- vitrified waste excluding C0 (having a higher thermal release) ;
- ″CU3″ waste (unprocessed spent fuels from research and defence) ;

ii) approximately 110 000 m3 of primary packages of IL-LL waste, which would correspond to approximately 360 000 m3 after conditioning for the disposal, including :
- cladding waste and technological waste conditioned in standard containers of compacted waste (CSD-C) ;
- bituminised effluents ;
- activated waste and technological waste conditioned in concrete containers ;
- deconstruction waste.

In addition, within the framework of the deep geological repository project, research programmes are being conducted in the Meuse / Haute-Marne underground research laboratory concerning notably the analysis of the transfers of radionuclides into the environment, the migration of gases, the evolution of the permeability of concretes according to the state of fissuration and the applied constraints, and the corrosion speeds in a disposal situation. An updated programme describing the research and development to be pursued in the perspective of confirming the acquired knowledge and investigating complementary techniques must be presented by Andra at the end of 2009 within the framework of the autorisation renewal application to exploit the Meuse/Haute-Marne underground research laboratory.

The human and social sciences (HSS) have also been integrated in the research conducted within Andra, notably in order to delineate the information and dialogue topic. This integration is ensured by HSS studies associated with the project within the framework of the scientific programme. It should be noted, in particular, that the set up of a specific programme on reversibility, which was concretised by a workday bringing together thirty participants and the selection of a doctoral thesis topic for Andra funding.

Storage of HL/IL-LL waste

Andra finalised in 2007 the programme of studies related to storage. This programme is based on the transfer of knowledge accomplished with CEA, in conformity with PNGMDR, and on evaluator recommendations. The main deliverables for 2009 concern the listing of storage needs in connection with the update of the national inventory of radioactive materials and waste, and the proposal of options in terms of storage.

The studies and research coordinated by Andra aim at developing storage facility concepts which best fit into a complementarity concept with the disposal for the optimisation of the HL and IL-LL management routes and in compliance with the principle of disposal reversibility adopted by law. The complementarity analysis between the storage and the disposal leads to a searching for ways to (i) reinforce the sustainability of future storage sites[20] up to a duration on the order of a century ; (ii) increase the multi-functionality of the facilities in order to accommodate waste packages of diverse origins and manage packages which would be removed from the disposal, if necessary ; and (iii) allow conditioning directly in disposal packages the waste intended for storage before disposal.

Among other things, thanks to its feedback, Andra identified the decisive processes with respect to the sustainability of the storage sites and the stored packages in order to conduct engineering studies and program the research under the best conditions. In particular, it is now confirmed that the sustainability and the robustness of a storage for a century will depend on :

[20] The operating duration generally considered for the existing storage facilities is fifty years.

- the control and the maintaining of the internal environment under dry conditions notably via design provisions related to air treatment ;
- a choice of adapted materials, especially stainless steels for zones potentially exposed to corrosion, specific concrete formulations to minimise atmospheric carbonation ;
- design solutions attenuating the various internal or external stresses.

First innovative technical solutions were explored to reinforce the universality of the future storage facilities for the HL/IL-LL waste. The perspective to create beyond 2025 HL waste storage facilities which already lived through a first half-life of thermal decay (see section 3.1.2) would offer a field of application particularly appropriate for these solutions.

In addition to the surface facilities, Andra studied shallow depth storage concepts according to two possible development methods : in an underground drift or in a covered trench. The studies disclosed a greater complexity of technical concepts in the drift. The advantages in terms of safety and robustness at the century scale do not appear decisive.

Conditioning HL/IL-LL waste

As a complement to the research conducted about the three orientations viewed above, studies are being conducted on the conditioning of HL/IL-LL waste.

Vitrification implemented successfully over several decades in the plants of Marcoule and La Hague is today in France the industrial reference process for the conditioning of fission product solutions originating from the reprocessing spent fuels (HL-LL waste). Studies were conducted to estimate the glasses' performances in the deep geological repository, as well as the dominating physical phenomena over the long term. Moreover, research on the effect of increasing the actinide content in the glasses disclosed a good behaviour by the glass under self-irradiation. This result led the Nuclear Safety Authority (ASN) to authorise at the end of 2008 the production of this package, allowing AREVA-NC to vitrify all the lots of fission product solutions without increasing the number of packages produced per tonne of processed fuels. Finally, a new vitrification process, which implements a cold crucible, indispensable for the vitrification of fission products with molybdenum (historical waste of La Hague), was refined by CEA. This process will be tested at the industrial scale by AREVA at La Hague by the end of 2009 for an industrialisation in 2010.

For IL-LL waste, three conditioning modes were or are used : compacting, cementation and bitumising. A task of acquiring knowledge has been accomplished since the Act of 1991, which was formalised, notably in descriptive package catalogues, and lead, in some cases, to operational models of package behaviour. One of the main issues to be studied in depth concerns the hydrogen resulting from the radiolysis of organic materials, which is the gas mainly released by the packages during the operating period of the disposal (Dossier Andra 2005). An R&D programme aimed at improving the modelling tools to forecast the production of hydrogen and identify the productions of water-soluble molecules, the degradation products of the polymers, liable to complex the radionuclides was set up.

2.6. The global consistency of the management of radioactive materials and waste

2.6.1. Evaluation of the exhaustiveness of the waste management routes

Schematically, three development levels for the various radioactive waste management routes exist today :

State	Categories
Existing final management routeVLLDC placed in operation in 2004	
	LL/IL-SLDC placed in operation in 1992
	Other existing management methods (disposals of mining residues and waste rocks, waste deposits with enhanced natural radioactivity, disposal centres of conventional waste)
Final management route under study (an active research process is being launched to define a management route)	HL/IL-LL
	LL-LL
	Tritium-bearing waste (CEA EDTSF project)
	Disused sealed radioactive sources
Still no existing final management route or at the project stage	Waste without management routes

Most of the radioactive waste has an existing final management route or a management route at the project stage. In particular, for tritium-bearing waste and disused sealed radioactive sources, a management strategy and solutions are now defined, which is a step with respect to the PNGDMR 2007-2009. However, some waste does not enter for the moment in any of the existing final management routes or at the project stage because of special physical or chemical characteristics. This waste requires a special processing and/or a special conditioning. The main waste types currently awaiting a management route are listed below.

Some spent oils and solvents	Some asbestos-bearing waste	Incinerable tritium-bearing waste
Irradiated beryllium reflectors	Absorbant fork of reactor	BF3 detectors
Irradiated lead	Irradiated aluminium	Irradiated cadmium
Uranyl nitrate	Waste with boric acid	Silica (ISOTOPCHIM) ^{14}C
Clean-up sludge of effluents	Special ash	Contaminated mercury
Lead tower	Cobalt waste	Hafnium waste
Bulb containing UF6	Tritium-bearing distillates	Heat transporting NaK
Porogene and lubricant		

In section 3.6.1, actions are proposed to remedy this lack of a final management route for some waste categories.

2.6.2. The necessity of optimisating the distribution of waste between management routes

For simplification, the current waste classification is focused on two major criteria, the level of activity and the half-life of the present radionuclides. In reality, many other criteria must be taken into account in order to determine whether a type of waste can be accepted in a management route : each of the current or future waste disposal centres is subject to long-term operating and behavioural constraints, which induce acceptance criteria in terms of physical form, chemical toxicity, thermal power, gas release, etc. (example below of the VLLDC).

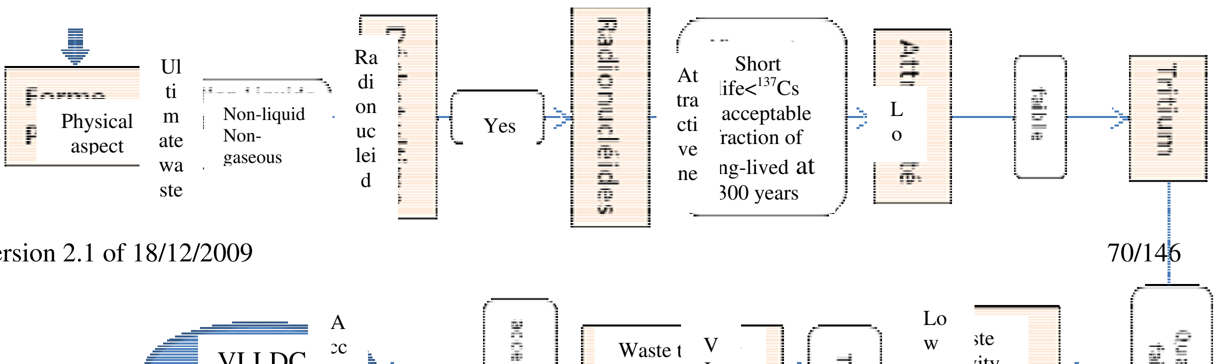


Figure 2. Acceptance criteria at the disposal centre for VLL waste

The situation is made complex not only by the number of criteria to be taken into account, but also by the fact that these criteria can evolve, notably after a new disposal goes into operation, or a new technology to process waste, condition it or dispose of it emerges. An optimisation of the waste distribution between management routes is therefore desirable, and must be periodically updated. Three examples are given hereafter.

Since the characteristics of the LL-LL and IL-LL solutions depend on the choice of sites and conditionings still not completely defined, the waste range intended for each of these solutions is still not definitively fixed, which induces a fuzzy boundary between both of these management routes. Some types of waste are therefore taken into account within the framework of both projects for precautionary measures. Further studies related to the processing and conditioning of waste, on the one hand, and to the development of the disposal projects, on the other hand, will give a clearer picture for the dimensioning of the inventories of each of the LL-LL and IL-LL management routes. By refining the disposal concept and the sites, waste acceptance criteria for disposal may be determined, thereby delineating the boundary between waste acceptable for LL-LL and IL-LL disposal.

The emergence of new solutions can lead to an adjustment of waste management in existing solutions : for the LL/IL-SLDC of the Aube, Andra is applying a prudent management policy for long lived radionuclides and it is possible that new management routes, notably LL-LL, will be better adapted to manage certain waste of this category.

Finally, the processing, sorting and conditioning of waste can modify the orientation between the disposals able to accommodate certain waste whose characteristics place them at the boundary between several potential solutions : between LL/IL-SL and LL-LL, between LL-LL and IL-LL, and between VLL and LL-LL, for example.

Work to assess more precisely the ways to optimise the distribution of waste between management routes is proposed in section 3.6.2.

2.6.3. Studies in the human and social sciences

In the perspective of a global reflection on the management of radioactive materials and waste, and notably in order to improve the overall consistency of their management, an initial series of studies was launched in the field of the human and social sciences.

In particular, in response to the previous PNGMDR (relayed by CNE), which assigned CNRS the task of watching over the pursuit of the ″reflection and study efforts in terms of sociology and the human sciences″, it was decided to launch in 2008 within PACEN the CNRS internal activity programme ACSSON (ACtion in Social Sciences On the Nuclear) detailed in section 3.6.3.

3. Improving the management of radioactive materials and waste

Based on the assessment detailed in the previous section, this section presents the actions to be undertaken to improve the management of radioactive materials and waste. It covers the improvement of the existing management routes, the consolidation of the management route projects under development, and the reinforcement of the consistency of the entire management structure.

3.1. The storage of radioactive materials and waste

3.1.1. Actions to be taken on old radioactive waste storages

Actions and studies to be taken on radioactive waste storages classified ″Basic Nuclear Facilities″

During the session of the High Committee for Transparency and Information on Nuclear Safety (HCTISN) of 23 September 2008, ASN had made within its field of competence a recommendation for the necessity of making sure that the timetables announced by the operators for the destorage and clean-up operations of the facilities be respected. These operations are too often delayed and it should be verified that safety level of the facilities pending a complete destorage remain acceptable (cf. section 2.1.2 of this report). Article 2 of the decree of 16 April 2008 related to the PNGMDR states that ″each producer or holder of radioactive waste must specify in his declaration [to Andra] the types of storage used, their estimated lifetimes, and the available capacities in case the final management routes for this waste are still at the project stage.″ Based on the waste producer declarations, this information is updated every three years within the framework of the national inventory (decree of 29 August 2008). The purpose of the following section is make an inventory of the actions engaged or to be engaged for each of the concerned sites.

The old AREVA storage sites at La Hague

The main problems encountered in the management of the old waste stored on the AREVA site at La Hague result from the lack of precise waste characterisation data, making it difficult to choose recovery solutions. Now producers, ANDRA and ASN are convinced about the absolute necessity of having waste characterisation data available for the elaboration of any new project in order to anticipate the conditioning resources which should be finally adopted. A part of this waste is still in a raw state or, in some cases, may necessitate a reconditioning. In conformity with the requirements of the Act of 28 June 2006, this operation should be completed in 2030.

The sludge of STE2
During the past few years, research and development actions were focused on the processing of the sludge from the STE 2 particularly to determine the recovery and transfer modalities to be complied with prior to any conditioning. Today, these modalities have only been acquired for two tanks, but they must be confirmed for the others. Efforts must also be applied to the conditioning itself. Thus, after the safety of the STE3 facility was re-examined, ASN decided to prohibit the bituminising of the STE2 sludge in the STE3 facility. In this same decision, ASN asked the operator to submit at the latest by 1 January 2010 a safety report corresponding to the required re-engineering arrangements to be made on the La Hague site in order to implement the conditioning method used as an alternative to the bituminising of the STE2 sludge. The processing capacity of these re-engineering arrangements should allow a recovery of this sludge at the latest by 31 December 2030.

The HAO and SOC silos
The decree no. 2009-961 of 31 July 2009 authorises Areva to dismantle the basic nuclear facility no. 80 denoted HAO and which includes the HAO and SOC silos in its perimeter. The decree imposes that the operator destore the HAO silo before the end of 2022. The operator presented a dismantling scenario which is broken down into five phases (from 2010 to 2020 for the HAO silo ; from 2014 to 2025 for the SOC silo) : the first two phases consist of recovering and conditioning the cladding waste and the technological waste of the HAO silo. The recovered waste will be transferred to the ACC workshop and conditioned in CSD-C packages. The third phase consists of recovering and conditioning the fines and resins. The fourth phase, the last phase for the HAO silo, consists of recovering the silo bottom waste using adapted mechanical equipment. The fifth phase consists of recovering the SOC waste before routing it to the ACC workshop. The recovery operations necessitate dismounting beforehand the equipment installed on the silo's slab, constructing the recovery cell, and qualifying the equipment to be used. The first dismountings have already been completed. Some processing management routes are under study (incineration of the technological waste, vitrification of the fines and resins). To optimise the deadlines, a simultaneous recovery of the fines and resins and the hulls and end-caps seems to be one of the actions to be privileged.

Silo 130
After the announcement in the report of the set up of a graphite waste disposal management route, the operator announced that he was reconsidering his strategy, but that the objective to recover before 2030 the waste contained in silo 130 was maintained. As a result, the operations would necessitate storing the recovered waste on the site. Within this framework, the operator's current project presents four phases. The first phase consists of transferring the UNGG waste before its storage in the D/E EDS workshop. The second phase consists of emptying and processing the silo's water in the STE facilities. The last two phases will allow recovering the silo's bottom waste and rubbish. ASN authorised in July 2008 the preliminary re-engineering work and notably the installation of the waste recovery and evacuation cells for routing the waste from the silo to the D/E EDS workshop of UP3 A pending the opening of a sub-surface disposal management route. The first in situ tests are programmed to begin in 2010.

The alpha waste of building 119
The waste recovery plan will allow recovering the alpha waste of building 119. At the end of 2007, 2700 old drums had already been processed ; 2300 remain to be processed. Around 2013, all the old waste of building 119 will have been recovered. Moreover, Areva is thinking about recovering inline the alpha waste originating from the French MOX fuel fabrication plants, as well as those of the La Hague site.

The old EDF storage sites

The silos of Saint-Laurent
The installation of the silos of Saint-Laurent-des-Eaux is not at the origin of a contamination of the environment, but necessitates a reinforcement of its confinement capacity. With this goal in mind, ASN granted its agreement to implement a enhanced geotechnical enclosure pending the removal of the contents from the silo, which is subordinated to the opening of the graphite waste disposal centre. The work to implement this reinforcement solution will take place during 2010.

The mounds of Bugey
Some very low level (VLL) waste could be managed in the past on the site or could be sent to conventional waste elimination centres, provided the waste's level of activity was deemed sufficiently low. This practice ceased after the adoption of the ministerial order of 31 December 1999, which included specific and reinforced provisions on the management of very low level waste originating from basic nuclear facilities. So, the very low level waste is stored by Andra at the disposal centre of Morvilliers. The case of the mound of very low level waste rediscovered at Bugey in 2006 forces the operators to examine the possibility of similar historical disposals existing in other INBs.
By mid-2010, the operators will propose a programme to verify that in the perimeter of their facilities or their centres there are no historical waste disposals centres which would have been omitted in the declarations submitted to Andra for the national inventory established in 2009.

The case of the mounds of Bugey does not constitute to date a real challenge in terms of radiological protection or protection of the environment, notably due to the very low activity contained in these mounds. However, it raises the issue of what will become of this type of waste when the nuclear facilities of the Bugey site are decommissioned and dismantled. EDF should notably indicate its intentions about what will become of this type of disposal, in particular, within the framework of the dismantling plan which is now required by the decree of 2 November 2007.

The old CEA storage sites

Centre of Cadarache

INB 22-PEGASE
The project for the recovery of the PEGASE plutonium-bearing drums and their conditioning in cemented packages for storage in the INB CEDRA remains top priority. CEA agreed to cease destorage operations on 31 December 2010. For fuels not containing araldite, CEA also agreed to terminate the destorage at the latest on 31 December 2010. These fuels will then be stored in the CASCAD facility after reconditioning (STAR facility).

INB 56 – Installed storage base of Cadarache

- For the pits, even though the initial strategy privileged a recovery methodology by waste type (starting with the immobilised conditioned packages of pits F5, F6 and the re-engineered cells of F3 to terminate a few years later with the recovery of the bulk waste originating from pits F1 to F4), a new strategy split the FOSSEA project into two sub-projects, FOSSEA-RFR for the recovery from recent pits and FOSSEA - RFA for the recovery from old pits. In particular, at the old pits, the recovery is conducted by pit, regardless of the waste conditioning, in order to avoid deferral until the end of the worksite the recovery of the bulk waste (since this waste is the most problematic for the environment in case the pits lose their leak-tightness). Therefore, the FOSSEA project provides for the recovery and reconditioning of all the packages for storage at CEDRA after a possible complementary characterisation and reconditioning. A document presenting the technical choices and safety options for the F3 pit was submitted to ASN in 2007. CEA was informed in July 2008 that at this stage the presented technical choices and safety options are satisfactory. CEA agreed to start the destorage of this pit. For pits F5-F6, CEA completed a safety file related to the recovery operations in April 2008. CEA agreed that the recovery of these pits would be terminated by the end of 2013.
- For the trenches, recovery began in 2005 after several test phases, but had to be suspended in September 2006 for safety reasons (stability of the trench's slopes of the cover). The recovery of this trenched waste suffered setbacks due to operational problems, an incorrect estimation of the volume of earth to be extracted before arriving at the waste, a underestimation of the waste volume and an incorrect evaluation of their activity (major alpha emitters). The worksite stopped since September 2006 should resume after the slopes of the cover on the trench being recovered have been reinforced and a new service provider has been selected.

Centre of Saclay

INB 35 – The destorage of the concentrates is underway and the recovery operations will be terminated by the end of 2013.

INB 72 -
In conformity with CEA engagements related to the destorage of fuel stocks stored in pools and in blocks and the preparation for the destorage of the fuels in shafts, the actions should be completed before 2017 for the fuels in blocks and pools and at the earliest in 2019 for the fuels in shafts. Many source term reduction projects are in progress.

Centre of Grenoble

The transition into the decommissioning and dismantling phase (MAD-DEM) of the basic nuclear facility INB 79 was covered by a decree which states that all the irradiating waste of INB 79 must be evacuated at the latest by 31 December 2010. The elimination management route passes through the storage and conditioning facilities of Cadarache (INB37, Cedra) or those of Saclay (INB 72). CEA has already engaged the evacuation operations.

Centre of Fontenay

The waste will be evacuated within the framework of the dismantling and clean up of the centre to final or temporary management routes (notably INB 36 and INB72).

Actions and studies to be conducted on storage facilities classified "Secret Basic Nuclear Facilities"

During the session of the High Committee for Transparency and Information on Nuclear Safety (HCTISN) of 23 September 2008, DSND recalled that it did attentively monitor the programmes of old waste recovery and waste package transfer to final disposals depending on the availability of the elimination management routes.

In the case of the INBS of Marcoule, for the waste still without an elimination management route, a strategy was devised based on work for the improvement of existing storages for old waste whose recovery cannot be rapidly accomplished (for example, waterproofing work on casemate roofs) and on the extension of existing facilities or the construction of new facilities to carry out old-waste recovery programmes (for example, additional cells of the "Multipurpose Interim Storage Facility" (EIP) or new storage of FMLL disposal packages, new UCDA workshop). However, for non-immobilised waste, which represents an important source term, DSND asked CEA for new improved safety proposals for the storage conditions and new recovery planning proposals with priority given to non-immobilised waste for evacuation to existing outlets or transfer to safer storages.
For HL waste (vitrified waste packages), the procedure for the re-examination of the safety of the storage facility of the Marcoule vitrification workshop led DSND to request CEA for demonstration complements in order to decide on the sustainability of this storage until the end of the recovery of the packages to emplace them in the deep geological repository. **Interfaces for shipping the HL and IL-LL packages to the disposal centre should be developed by CEA taking into account the technical possibilities in terms of transport, estimated needs in controls and reconditioning for the disposal, and the possibilities of disposing of them over time. The technical options and a first analysis of the transport modalities will be identified by CEA in concertation with Andra for the end of 2011**, notably for the presentation of storage-transport-disposal scenarios in the upcoming public debate on the deep geological repository project.

For the INBS of Pierrelatte, the diffusion barriers and the technological waste present in "the mound" must be evacuated to the Andra disposal centres before 2013. The evolution of fluorines and chromium-rich sludge is under study. DSND asked the operator for the historical record of the waste pits of the North zone, as well as a rehabilitation plan. The characterisation, recovery, conditioning and evacuation of the waste to an authorised management route are under study.

For the tritium-bearing waste of the INBS of Valduc, the safety conditions of the current storages of tritium-bearing waste in the short- and medium-terms are deemed satisfactory ; the long-term solutions studied are consistent with the orientations presented in the study submitted by CEA at the end of 2008 in conformity with the PNGMDR decree for the waste categories produced on this site.

Generally, the recovery of waste necessitates defining the conditioning solutions and therefore, as a minimum, knowing the main criteria – or else the details – of the packages specifications for the disposals under study. Therefore, this work requires exchanges between the waste producers and Andra.

Actions and studies to be conducted on the storage facilities excluding the "Basic Nuclear Facilities" and the "Secret Basic Nuclear Facilities"

The Rhodia site at La Rochelle

The evolution of the materials stored by Rhodia at La Rochelle is discussed in section 3.2.1.

The CEZUS Company site at Jarrie

The management conditions for the waste stored on the CEZUS Company site at Jarrie are satisfactory and do not call for actions in the short term. The recovery conditions for this waste were discussed and the retained elimination management route is that of the low level and long lived waste disposal centre. According to the operator, storage capacities allow satisfying the waste production previsions in agreement with the calendar for the commissioning of the LL-LLL waste disposal centre.

The COMURHEX site at Malvési

The storage of waste in the settling basins necessitates arrangements for pursuing the improvement of the waste's confinement and limiting the transfer of contamination to the water table. For some basins, an administrative amendment provides for an INB classification considering the evolution of their exploitation, the stored quantities and the presence of artificial radionuclides originating from past industrial activities of the facility (utilisation of reprocessed uranium).

AREVA will submit a study at the end of 2011 proposing safe long-term management routes for waste contained in basins, as well as management modalities for new waste produced by the operation of the facilities.

Moreover, after the work initiated within the framework of the ″COMURHEX II″ worksite of Pierrelatte, COMURHEX turned to the processing of excavated earth tagged with reprocessed uranium. In the absence of a management route, COMURHEX will eliminate all the earth tagged with reprocessed uranium for Andra at the latest by 1 July 2014. During these work phases, a reinforced monitoring of the piezometers downstream from the underminings to be set up will allow controlling any contamination of the water table.

3.1.2. Storage facilities creation projects

The analysis of the adequacy between storage capacities and radioactive waste volumes for which there is still no long-term management route remains to be clarified for some waste categories, in particular, for radium-bearing waste. In order to complete the assessment presented in section 2.1.4, **Andra will analyse in concertation with the operators the adequacy of the storage capacities available for the LL-LL waste with the estimated inventory of this waste and the possibilities of disposing of the LL-LL waste.** This analysis will be conducted at a time to be determined in consistency with the future evolution of the LL-LL waste project.

Based on the existing assessment (cf. 2.1.4), the main lines of the required storage creations and extensions can already be anticipated. They are presented hereafter at various time horizons : before 2015, between 2015 and 2025, and after 2025.

Creation or extension of storage facilities by 2015 (except for tritium-bearing waste treated in section 3.5.1)

As a complement to the existing storage facilities on the waste production sites, the creations and extensions of facilities foreseen by AREVA, CEA and EDF by 2015 will allow satisfying in terms of capacity and lifetime the storage needs linked to the HL and IL-LL waste packages produced around this horizon.

The corresponding projects are : the extension of the glass package storage in the Southeast zone (E-EV-SE) at La Hague (Areva), the realisation of sections 2 and 3 of the radioactive waste conditioning and storage facility (CEDRA) at Cadarache (CEA), the creation of the DIADEM facility at Marcoule (CEA) and the creation of the activated waste conditioning and storage facility (ICEDA) on the Bugey site (EDF).

As a result of the cooperation between Areva and Andra on the extension project at La Hague, the design evolutions and observation provisions could be integrated to allow better sustainability prospects than for the existing facilities.

The collaboration between the operators of storage sites and Andra will thus be developed to capitalise on the feedback acquired from the design, construction and operation of the facilities and reinforce the complementarity between the projects of storage facilities on production or conditioning sites and the future deep geological repository.

Within this framework, EDF and Andra will cooperate on the design of the ICEDA storage, in particular, the observation and monitoring provisions which will allow following under the best conditions the evolution over time of the storage structures and the stored packages. In addition to the IL-LL packages, ICEDA will accommodate in-transit packages of the LL/IL/SL management route, as well as LL-LL packages awaiting to be disposed of.

Moreover, **Andra will create a storage facility for diffused nuclear sector waste aiming at an industrial entry in operation in 2012.** The concerned waste belongs mainly to the LL-LL management route and originates notably from historical activities, such as the handling and utilisation of radium in the first half of the 20th century. This facility could be coupled to a collecting facility of waste from "small producers" (hospital/university and research sector) and would have a capacity evaluated today at approximately 3 500 m^3.

Creation or extension of storage facilities from 2015 to 2025

In the decade 2015 – 2025, other creations or extensions of storage facilities will be necessary. The following are concerned on the production or conditioning sites :

- the storage of packages of bitumised sludge and solid waste at Marcoule awaiting to be disposed of in addition to the multipurpose interim storage facility (EIP) ;
- an extension of the storage capacities of cladding and technological waste compacted at La Hague (ECC) ;
- a new extension of E-EV-SE at La Hague.

Beyond the utilisation of storage capacities available at Marcoule (see section 2.1.2 and the corresponding annex), placing the waste in EIP drums does not seem to be the most appropriate strategy for bituminised sludge packages. A more favourable strategy consists of placing them directly in a disposal container on the Marcoule site[21]. This strategy may be extended to the IL-LL solid waste of the Marcoule site.

This option globally reduces the number of package transfers and handling operations to be performed. It offers for bituminised sludge packages a very important gain in disposal resources by reducing (on the order of 40 %) the final volume of disposal packages. The disposal volume and cost are reduced.

The waste may be placed in a IL-LL disposal container on the Marcoule site as of the authorisation date of the creation of the deep geological repository (that is, around 2017). The final design of the container may thus integrate the requirements from the future Act setting up the reversibility conditions, as well as the technical prescriptions following the evaluation of the disposal creation authorisation application. However, such a strategy supposes that the design and construction of the conditioning workshop are ahead of the acceptance specifications for the disposed packages, which likewise may only be finalised after the creation authorisation is granted. The conditioning workshop design will be sufficiently flexible to adapt to the evolutions in this container's specifications.

Such a strategy extended to solid waste does not necessitate the construction of additional cells at the EIP. On the other hand, IL-LL disposal packages constructed starting from 2017 will have to be stored in a new storage capacity to be commissioned in 2017. This new capacity will also have to

[21] In the Dossier 2005 on the deep geological repository, all the bituminised and solid waste of Marcoule was envisioned to be placed in disposal containers on the disposal site.

accommodate packages linked to the LL-LL waste management route and which will also be conditioned in a disposal container on the site.

The disposal of the packages containing bituminised IL-LL sludge and potentially solid waste originating from Marcoule as of the date of entry in operation of the deep geological repository opens the possibility of an overall optimisation of the system by limiting the new storage capacities to be created. CEA and Andra will study this scenario in a concerted way by the end of 2012.

The study will treat, in particular, the feasibility of the disposal containers with respect to their design, the design of the storage facility to be created[22], the transport possibilities up to the disposal centres, and the disposal possibilities over time when the reversibility[23] of the deep geological repository is taken into account. This study will be monitored by a working group uniting CEA, Andra, DSND and ASN. Considering the place of transports in the operational character of this scenario, CEA will analyse their possibilities and limits for 2010.

Areva, Andra and EDF will study for the end of 2012 the destorage and transport scenarios for packages containing compacted cladding and technological waste (CSD-C), as well as the needs in additional storage capacities to be created by 2025 on the La Hague, taking into account a possibility of disposing of CSD-C packages by the decade 2025-2030.

Areva, EDF and Andra will analyse by the end of 2012 the theoretical feasibility of integrating the E-EV-SE extensions at La Hague into the reversibility support system[24] of the deep geological repository with a view of presenting storage-transport-disposal management scenarios at the upcoming public debate on the deep geological repository project.

In parallel with the aforementioned projects, **Andra and the concerned LL-LL waste producers will examine the interest and the possibilities of integrating additional storage capacities in the future shallow depth disposal centre or on the production or conditioning sites in order to offer a greater flexibility in the management of this waste**. Families of potentially concerned waste will be identified, taking into account the existing storage capacities and the waste production perspectives ; the capacities to be provided for will be estimated in connection with the possible operating schemes of the disposal centre.

Creation or extension of storage facilities beyond 2025

In the decade 2025 - 2035, new storage needs will be linked to the industrial activities of the UP2-800 and UP3 plants of La Hague, notably with the start-up of the reprocessing of the MOX fuels in dilution with the UOX and URE fuels, and with the pursuit of the operations of recovery and conditioning of old waste (for which the Act programs the completion for 2030), or reconditioning of old packages at Cadarache, Marcoule and La Hague. The sludge conditioning packages of the STE2 station of La Hague are still under study ; their volume will determine precisely the storage capacities to be respectively mobilised in the S and SE buildings of the site.

The production of solid waste packages cemented in a fibre-reinforced concrete container CBF-C'2 and alpha waste packages will continue beyond 2040 with the dismantling of the UP2-800 and UP3 plants.

[22] CEA launched the project under the designation pending evacuation facility (IAE).

[23] The disposing of LL-LL waste may imply the availability of a storage capacity to accommodate packages with the eventuality of a removal from the disposal. Thus, this capacity would have to be created on the disposal site or a storage facility would have to be used on the production site.

[24] A potential capacity to accommodate HL waste packages which would be removed from the disposal could be located on the disposal site or be removed from the storage sites to be created at Marcoule or at La Hague. Studies on the storage done from 2006 to 2009 indicate that a mutual interconnection of the system between the HL waste of Marcoule and La Hague would be technically imaginable.

The final decommissioning of the storage facilities of the solid waste packages : EDS/ADT2, EDS/EDT-EDC, and the sludge packages : The S and ES buildings of La Hague, which are simultaneously scheduled today for 2040, should be anticipated. Disposing in the deep geological repository of the IL-LL packages which are stored there is imaginable starting from the decade 2035-2045. In parallel, a partial renewal of the storage capacities will be necessary. The facilities to be created around 2040 will allow especially following and monitoring the decrease in the release of hydrogen from the packages of compacted alpha waste if this conditioning method is retained.

The EIP storage at Marcoule and the CEDRA storage at Cadarache have an expected operation lifetime of 50 years. This will also be true for the facilities to be created by 2015 (DIADEM, ICEDA). In the light of an optimisation of the IL-LL waste management route, this will open the possibility of deferring the disposing of the waste packages which are or will be stored there.

The final decommissionings of the storage facilities of the vitrified HL waste packages : R7, T7 and E-EV-SE at La Hague, and spent fuels : CASCAD at Cadarache are programmed today for 2040.

It is imaginable that the least exothermic families may be disposed of around 2040. However, a large part of the HL waste packages of La Hague will only be acceptable for disposal after at least 60 years of storage, that is, 2050 for the oldest packages of this type (the F1-3-01 family of the national inventory). This deadline, combined with the production of packages beyond 2040, will lead to new storage capacity needs. Around 2050, the question may be raised whether the first packages of the F1-3-01 family may be disposed of or the storage phase by thermal decay may be extended ; such an extension would allow reducing the consumption of disposal resources, but would induce additional storage needs and would modify the disposal's operation chronicles. The advancing of the needs for HL waste demonstrates the necessity of a modular organisation of the storage system. Beyond 2025, it will become possible to design storage modules to accommodate the HL waste packages whose thermal power will have previously decreased (typically on the order of 700 to 1 000 W, instead of 2 000 W considered for E-EV-SE and its extension).

Andra will specify by the end of 2012, in concertation with the waste producers, imaginable management scenarios for all the HL and IL-LL waste packages intended for the deep geological repository project. The storage, destorage, conditioning, transport and disposing of chronicles will notably be studied, as well as the resultant storage needs, for the upcoming public debate on the disposal project. The producers will consistently define the transport solutions to be implemented and will verify with Andra the compatibility of these solutions with their current and future facilities.

It will be necessary notably to analyse the relevance of providing for storage needs beyond 2025 with storage capacities integrated in the deep geological repository instead of creating or extending facilities on the production or conditioning sites. This would consist of either mobilising the facilities required in any case for the transit of packages on the centre (between their arrival from the production or conditioning sites, their unloading and their inspection, their possible conditioning in a disposal container and their transfer in underground facilities), or creating facilities dedicated to a waiting storage. The option of a storage of HL waste on the disposal site for a second thermal decay phase belongs to the second case. Thus, studies of HL and IL-LL waste package management scenarios will compare, for the public debate, the option of a storage on the disposal centre when it is imaginable with that of a storage on the production or conditioning sites, regarding the safety plans, the impact (environmental and socio-economic), the cost, and the reversibility.

The estimated operation lifetime of this future generation of storage facilities is on the order of one hundred years, which is consistent with the estimated operation lifetime of the deep geological repository, the thermal decay of the HL waste and the reversibility term of at least one hundred years fixed by law.

The conclusions of all the work requested in this section (3.1.2) for the HL/IL-LL waste will be summarised by Andra in the dossier on storage which it will submit at the end of 2012 (cf. 3.5.4).

The conclusions of the work requested in this section concerning the LL-LL waste will also be summarised by Andra in a report to be submitted at a time to be subsequently determined depending on the evolution of the LL-LLL waste project (cf. 3.5.4).

3.2. The long-term management of reusable materials

3.2.1. Research on the knowledge and behaviour of certain materials

Knowledge about the evolution of spent fuels over long periods deserves a thorough review. In fact, only a part of the UOX fuels are currently being processed, the rest of the UOX fuels and MOX fuels is stored. Still, the deferred processing of these fuels is planned in consistency with the possible deployment of an installed base of 4th generation reactors, which leads to industrial storage durations in the pool beyond current feedback. **Therefore, studies and research will continue to be conducted on the behaviour of spent fuels (UOX and MOX awaiting reprocessing) over the considered storage durations, especially on the evolution of the cladding and the assembly under transport and extended underwater storage conditions.**

3.2.2. Valuation of the reusability of radioactive materials

Spent fuels

Most of the spent fuels are reusable materials. In particular, the reusability of civil uranium-based spent fuels is an operation already widely implemented at the industrial level for UOX fuels. For MOX fuels containing plutonium, the reprocessing feasibility was demonstrated. Likewise, except for small quantities of some spent fuels from research reactors (cf 2.2), the reprocessing feasibility at the industrial scale of fuels from research and navy nuclear propulsion reactors is confirmed.

Uranium and plutonium

The elements described in section 2.2 show at the industrial level the reusability of the materials produced by the ″uranium″ management route and the ″plutonium″ management route from the production of electricity. However, **the nuclear operators will also specify by the end of 2010 the evolution of uranium originating from a second possible recycling and will analyse the reusability or non-reusability of the spent fuels originating from the heavy water reactors EL1, EL2 and EL3 and the UNGG reactor G1.**

Depleted uranium is potentially reusable. It can be :
- enriched like natural uranium ;
- used in MOX fuels ;
- used in potential future 4th generation reactors. These technologies will allow taking advantage of all the energy potential of uranium by consuming uranium 238, today not reused (the enrichment of depleted uranium allows reusing the content of uranium 235, but not that of uranium 238).

The already effective availability of the first two reusability management routes alone justifies that depleted uranium is a radioactive material in the sense that its utilisation is anticipated or considered.

For the uranium 238 contained in depleted uranium, whether originating from reprocessing or not, it may be reused in the very long term in 4th generation reactors. It represents a resource for several thousand years. This is due both to the expected high performance of the 4th generation reactors and to the fact that natural uranium contains approximately 150 times more uranium 238 than uranium 235.

It goes without saying that preserving this resource does not mean that these materials should be managed today under the best environmental conditions. Obviously, if the 4th generation reactors could not be developed, these materials would become waste once their uranium 235 content is no longer interesting. Then, they should be managed like waste over the long term. This long-term strategy is part of the programme of sustainable management of radioactive materials and waste fixed by the Act of 28 June 2006 .

For plutonium, EDF considers that the total quantity of plutonium mobilisable by 2040 (including in the spent fuels and the ″last cores″) should be on the order of 505 to 565 tonnes. This quantity should allow starting up approximately 25 fourth generation 1450 Mwe fast neutron reactors of the type proposed in the CEA studies according to a chronicle dependent notably on the capacities to process spent fuels. The order of magnitude of the quantity of plutonium available by that time is therefore consistent with a progressive replacement scenario of the current installed base by fourth generation reactors. The reusability of the plutonium stock expected for 2040 is therefore confirmed.

Suspended matter

The Rhodia study mentioned in 2.2 identified the perspectives of processing and reusing the rare earths contained in the company's owned suspended matter. The reusability of this matter is thus confirmed.

Thorium

For thorium-bearing matter, no management route is operational today to reuse the quantities held by AREVA and RHODIA. In addition, there are strong reservations about the development of a reusage management route in the short- or medium-term thanks to reactors using thorium as a fuel. The development of management routes and the design of various types of reactors using thorium still necessitates to be resolved a major research and development initiative. Also, the saving of uranium resources which would result from this management route this process remains to be demonstrated. In view of these strong reservations about the perspectives of reusing thorium in the short- or medium-term, specific recommendations are presented in section 3.2.3 in case this material would be finally considered as waste.

3.2.3. Management options if materials should be considered as ultimate waste

The reuse of most of the radioactive materials assumes that electronuclear programmes will be pursued in the future in France or abroad. Insofar as it cannot be guaranteed that this condition will be fulfilled at a very distant date, it seems important to examine the possible management options for these materials if they should eventually be considered as waste.

As a conservatory measure, spent fuels have been systematically included in the feasibility studies of geological disposal concepts, which also allowed comparing more easily French and international concepts ; a large number of countries provide the direct long-term disposal of spent fuels without reprocessing.

On the other hand, the long-term management options in case other materials, such as depleted uranium, are not reused would necessitate more in-depth investigations. The properties of depleted uranium in terms of radiological content are, in fact, some tens of thousands of Bq/g with long lived radioelements. The situation is notably different in the case of mining residues or radium-bearing waste for which the radioactivity is diffused in a large volume of non-radioactive material. Thus, depleted uranium may be considered neither as a VLL waste (the limit for uranium 235 and 238 at the VLL waste disposal centre is 100 Bq/g), nor even as a waste disposable on the surface in facilities currently in operation (reception limits for alpha emitters at the Aube centre are 3700 Bq/g on the average per package, but 370 Bq/g on the average in the entire disposal).

Therefore, it is necessary to examine what type of disposal would be compatible with the properties of depleted uranium. In any case, the orders of magnitude of the considered volumes, should these materials be considered as waste, will no doubt significantly alter the scope of the disposal projects. Therefore, it should be pointed out that if these materials would be considered one day to be waste, it would be necessary to take them into account in order to size the corresponding long-term management routes ; they could not be marginally dealt with like for some historical waste.

In this context, in consistency with the prescriptions of the previous PNGMDR, **all the owners of reusable radioactive materials will conduct before the end of 2010 as a conservatory measure studies on possible management routes in case these materials would be qualified in the future as waste.**

For the special case of thorium, AREVA and RHODIA will conduct more in-depth studies on possible management routes in case these materials would be qualified in the future as short-, medium- or long-term waste. In particular, they will examine in collaboration with Andra the possibility and the consequences, notably in terms of surface disposal, design and cost, of taking charge of them in the existing or envisioned disposal centres. Moreover, reflective thinking will be devoted to the opportunity and feasibility of a mechanism to financially secure the long-term management of these materials in case they would be qualified in the end as waste.

Finally, to be more specific, studies on the long-term behaviour of spent fuels which would be disposed of without any prior reprocessing will be pursued in a CEA-EDF-Andra partnership (notably concerning the influence of the site water composition and environment materials on alteration). These studies should allow creating by the end of 2010 a model for the release of radionuclides, whose objective is to be less demanding than that retained for the Dossier 2005. On this basis, Andra will verify that the disposal concepts (in particular, the design of the ramp and the shafts) remain compatible with the hypothesis of the direct disposal of spent fuels. Studies on the fuels from nuclear propulsion systems and research reactors will benefit from those on the REPs for fuels in an oxide form.

3.3. Long-term waste management : disposal centres dedicated to radioactive waste

3.3.1. The VLL waste management routes

Optimising the consumption of the VLLDC capacity

As indicated in section 2.3.1. of this report, the annual consumption of the volume capacity of the VLL waste disposal centre of Morvilliers is increasing, which justifies studying new ways to optimise the management of VLL waste. What is to be avoided is that the maximum capacity authorised by the prefectorial order is reached in 20 or 25 years instead of the anticipated 30 years. Moreover, following the principles set forth by the Act of 28 June 2006, the volume available for the disposal of waste must be considered to be a rare resource to be preserved. Several proposals described hereafter would allow fulfilling this objective, which was already mentioned in section 1.2.2. of this report.

A solution to optimise the disposal capacity of the VLLDC consists of reducing the delivered flows by trying wherever possible to reuse a part of the produced waste. Initiatives were taken, in particular, for the metals originating from the dismantling or the maintenance of nuclear facilities, such as lead, copper, or steels. By the end of 2011, the producers of very low level radioactive metal waste and Andra should make an assessment of the actions provided for or engaged in the matter, and evaluate with the nuclear operators who can use finished products built with metallic materials in nuclear facilities, for which the disposals, the feasibility and the opportunity of an industrial scheme would allow the recycling of the metallic materials originating from the dismantling of the facilities in the upcoming years. To help make this assessment, a working group bringing together the various concerned parties will be formed.

The dismantling of facilities will generate large quantities of concrete. The approach on which their management is based today calls for the creation of a disposal in the proximity of the INBs. The study on the replacement of fresh sand by crushed VLL concretes as the material to use to fill the empty spaces in the cells of the VLL waste disposal centre may be envisioned. Andra in connection with the concrete waste producers will submit by the end of 2011 a report on the interest and the feasibility of recycling these crushed materials, for example, by using them instead of fresh sand to fill the empty spaces in the VLLDC. Andra will conduct this study, if necessary, with other potential users of the recycled crushed materials (in the nuclear management route) requesting to participate.

Moreover, if the density of the waste to be delivered in the future to VLLDC does not increase with respect to the average density of the waste delivered since the disposal went into operation, the disposal capacity will be consumed more rapidly than expected in the design. Aware of this situation, Andra and the main waste producers agreed that it would be necessary to examine the technical possibilities and the economic opportunity of densifying the waste delivered to the Morvilliers centre in order to approach the objective initially defined at the opening of the centre. This approach can be concretised by a prior processing of the waste before delivery or by a more sustained utilisation of the VLLDC's presses. All these reflections will be included in a joint report by CEA, EDF and AREVA to be submitted before 30 June 2011. The report will present a technico-economic evaluation of the scenarios which they imagine will increase the average density of the waste delivered so that the waste to be disposed of at VLLDC will have an average density close to the density defined with the producers during the disposal's design.

Subsequent to the studies to be submitted in 2011 on the recycling of metallic materials, the recycling of crushed materials and the densifying of the waste to be delivered, Andra will make by mid-2012 an assessment of the impact of these efforts on the VLLDC's operation lifetime and will present it to the PNGMDR working group. Based on five years of feedback from VLLDC, Andra will propose for mid-2011 an optimisation of the operating rules and the conditioning specifications (scrap iron caissons, etc.) to favour a better disposal density in the cells.

Improving the accommodation of large size waste

Subdividing waste to condition it in the standard packages received at VLLDC is not always the most appropriate solution. VLLDC can accommodate massive parts up to thirty tonnes thanks to special handling resources. Above 30 tonnes, it is necessary to make arrangements to stabilise the waste block on which these massive parts are laid.

Based on an estimated inventory of large size waste, Andra will examine by the end of 2011 the interest in developing an industrial management route to accommodate this waste in dedicated disposal cells equipped with adapted handling means.

The relevance of a disposal ″as is″ of this kind of waste will be appraised according to the same method as that developed for LL/IL-SL waste (see section 3.3.2).

Examining the different approaches in the management modalities between the VLLDC and technical landfill centres

Among the ways of improving the management of the VLL waste management route is the management of the chemical toxicity of waste intended for the VLLDC. In fact, the impact study supporting the authorisation application for the creation of the VLLDC is based on a methodology distinguishing the potential long-term impact of chemical toxics present in the waste : this methodology leads to the distinction between chemical toxics whose effects are felt above a certain concentration (thresholded effects), such as lead or mercury, and chemical toxics with stochastic effect (the probability of the occurrence and not the severity of the effect is proportional to the dose of exposure), such as cadmium or arsenic. Such an approach limits the chemical toxics in the disposal and guarantees a satisfactory long-term safety level in addition to limits applicable to each waste lot. This leads to problems for the accommodation of certain hazardous waste, especially waste containing asbestos.

Still, this waste would not be subject to such restrictions if it did not belong to the nuclear waste category. In fact, regulations applicable to ultimate waste disposal centres (or technical landfill centres) do not demand a study of their long-term safety.

For the end of 2011, Andra will submit a comparative study of the safety approaches implemented in ″ultimate waste″ disposal centres and in the ″very low level radioactive waste″ disposal centre. If necessary**,** the interest in harmonising these approaches will be examined. In the case of radioactive waste, proposals will be made for the most relevant way of orientating waste to the different existing disposal management routes or management routes under development according to their chemical toxicity.

3.3.2. The LL/IL-SL waste management route

The Manche disposal centre (CSM)

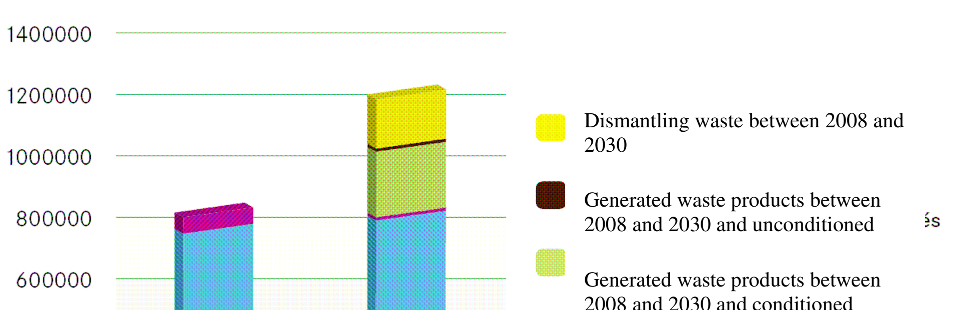
Radioactive waste management includes not only its conditioning and its accommodation in a disposal, but also the monitoring of the disposed waste. In this sense, the feedback from disposals in the monitoring phase, such as the Manche disposal centre where waste produced up to 1994 has been disposed of, provide invaluable information for existing disposals or proposed disposals.

At completion of the ASN evaluation by the end of 2009 of the report communicated by Andra on the CSM covering, an action plan will be elaborated along with a timetable. This plan will be presented by Andra within the framework of the PNGMDR. The report's evaluation will also be an occasion to make an assessment of the evolution of the contamination of the water table and the environment by tritium and, if necessary, to undertake other monitoring and control actions. Andra will also periodically report on the evolution of the contamination of the water table by tritium to the working group's members.

In any case, it is likely that the covering's surface after work will lead to an extension of the Manche disposal centre (CSM). The availability of the contiguous lands to the CSM, in particular, the lands currently owned by AREVA, will necessitate on the part of Andra a watch on the land availability in order to be able to acquire, if necessary by pre-emptively some lands.

The LL/ILDC

The 2009 edition of the national inventory of radioactive materials and waste showed at the end of 2007 a volume of already produced low or intermediate level and short lived waste of approximately 793 000 m^3. This volume was calculated after conditioning, including approximately 3 000 m^3 of tritium-bearing waste. At the end of 2007, the volume already disposed of was approximately 735 000 m^3. The volume of waste remaining to be conditioned and to be disposed of (excluding tritium-bearing waste) corresponds approximately to 5 years of LL/ILDC operation at the current accommodation rate.



Monitoring of the disposed of LL/IL-SL waste volumes and pending disposal

Following the publication of the 2009 edition of the national inventory of reusable radioactive materials and waste, **Andra and the waste producers will periodically report on the evolution of the waste volume in storage and the provisional calendar for its conditioning and disposal. An assessment will still be made in 2012.**

Accommodating the LL/IL-SL waste outside of dimensional standards

As an extension of the accommodation of reactor tank covers, other large-size waste disposal operations are planned or under study, for example, concerning the Chooz A reactor tank or declassified shipping casks.

It seems, however, that the relevance of this disposal option with respect to a conditioning in standard packages must be assessed for each object by examining whether it is globally optimal from the viewpoint of dismantling operations (complexity of the ″splitting up″ operations, dosimetry of the personnel assigned to these operations, etc.) and transport (necessary road arrangements, etc.), but also the disposal (bulking of the waste during the ″splitting up″ and consumption of the centre's capacity, impact on long-term safety, etc.).

Inspired by the international approaches on this issue, Andra and the concerned waste producers will propose for mid-2011 a document indicating the criteria on which the relevance of the disposal of large-size LL/IL-SL waste after decontamination can be evaluated.

The disposal of waste containing tritium

Feedback from CSM stresses the need to carefully examine the reception of waste containing tritium at LL/ILDC. Knowledge about the gaseous transfer mechanisms in LL/ILDC, with special attention paid to tritium, the most mobile element, must be extended. Based on these elements, and the resumption of safety studies**, Andra and the producers will expose their reflections by the end of 2011 on new acceptance criteria at LL/ILDC for waste containing significant quantities of tritium.**

3.4. Long-term waste management : other existing management routes

3.4.1. Mining residues and waste rocks

Even though the in situ management of the ore processing mining residues and the waste rocks is acceptable considering the volume and the characteristics of this type of waste, the long-term institutional monitoring and the consequences in case of an unsuitable utilisation in the future of the concerned lands should be more precisely studied. In fact, the natural radioelements present in the mining waste have long lifetimes and emit radioactive descendants in a gaseous state (radon). AREVA should pursue its studies on the long-term safety of the mining residues disposal sites and on the improvement of the monitoring to be implemented on other old mining sites, notably on the conclusions at the end of 2009 of the reflections of the GEP on the long-term institutional monitoring of the mining residues disposal sites.

Moreover, it should be recalled that these old sites must be managed in conformity with the action plan established by the circular of the Ministry of Sustainable Development and ASN of 22 July 2009 and by the letter of the AREVA Company of 12 June 2009 addressed to the Minister of State. This action plane is designed around the following measures :

- Control old mining sites ;
- Improve knowledge about the sanitary and environmental impact of the old uranium mines and the monitoring ;
- Manage waste rocks : be better informed about their utilisations and reduce the impacts, if necessary ;
- Reinforce information and concertation.

The disposal sites of ore processing mining residues

The AREVA assessment made within the framework of the implementation of the national plan for the management of radioactive materials and waste is a decisive milestone in the approach to verify the safety of the uranium ore residue disposals. The documents submitted within the framework of this assessment allow judging today the state of knowledge on two key points which are : the characterisation of the residues and the behaviour of the dikes surrounding some disposals. It should be noted that the approach implemented by AREVA is consistent with the methodological framework defined by BRGM upon request by the Ministry of the Environment for this type of disposal. These documents also provide a first indication of the expected impacts for a normal disposals evolution scenario and for a set of degraded evolution scenarios.

Even though the Areva conclusions are credible foundations to establish the long-term safety of the uranium ore processing residues disposal facilities, they, nonetheless, necessitate complementary studies and analyses to justify them better and reinforce the long-term safety demonstration of the residues disposals. The main complements expected from Areva are detailed hereafter.

Concerning the evolution of the long-term physico-chemical characteristics of the ore processing residues, AREVA should pursue the characterisation studies by exploiting the data coming from the Brugeaud, Bellezane, and Lodève sites by completing them as well as conducting a new sampling campaign on the sites selected for their relevance. From the obtained results, Areva will elaborate for the end of 2012 geochemical models to simulate the various disturbances imaginable during the evolution of the disposal and will analyse whether these results can be generalised to the ore processing mining residues disposal sites not covered by an on-site characterisation study.

For the evaluation of the behaviour of the dikes surrounding the ore processing mining residues disposals, AREVA should by the end of 2011 complete its geomechanical evaluation approach by specifying the requirements which it retains to evaluate the long-term safety of its disposals by making sure notably that retained dikes' stability duration is consistent with the turn-around time for the considered natural incidentals and by taking into account the consequences on the structures as soon as the monitoring and servicing actions are stopped.

For the evaluation of the long-term radiological impact of the uranium ore processing mining residues disposals, AREVA should thoroughly exploit the results of the dosimetric impact evaluations made in 2008, on the one hand, to verify their relevance with respect to the available measurement data on each of the sites and, on the other hand, to systematically identify the possibilities of reducing the impact of the ore processing mining residues disposal sites today and over the long term on the populations. **To this end, Areva should study by the end of 2011 the reinforcement of the quality of the coverings which, in light of the results of the long-term impact evaluations, seems to be a potentially efficient solution on several sites in order to evaluate the feasibility and the relevance on all the mining ore processing residues disposal sites.** AREVA should also improve its knowledge about the atmospheric transport of radon from the disposal sites to the surrounding environment and the relevance of its radon transfer modelling computations from a disposal to a habitation assumed to be constructed directly above it in the case of a degraded evolution scenario.

Generally, the Areva engaged studies are recent and focus on the measurements and observations made within the framework of the monitoring of its sites. However, it is necessary to acquire data over a sufficient time interval and on a number of representative sites. Therefore, this long-term research work may be spread out up to 2020, milestones being programmed every 3 years on the occasion of the PNGMDR updates.

The mining extraction sites

Within the framework of the mine action plan set up in 2009 by the Ministry of Sustainable Development and ASN, and to improve knowledge about the sanitary and environmental impact of the old uranium mines and their monitoring, several actions are provided for. Areva should thus within three years re-evaluate the environmental monitoring of all the mining sites (their ancillary buildings, processing facilities and mining residues and waste rocks disposals, etc.) in order to define, if necessary, a still better adapted monitoring. Areva should also pursue the rehabilitation of the old sites requiring it for the purpose of perfectly integrating them in their local environment and over the long term. Inventory studies underway within the framework of the Mimausa project and residual risk analyses within the framework of the mines action plan should lead to, if necessary, the re-engineering of sites by Areva or accompanied, for example, with utilisation restrictions (mentioned in a local urbanism plan) for these lands.

It seems important to insist on the necessity of reducing diffused discharges and improving the processing of the discharges (by privileging ″soft techniques″), in particular with respect to the impact on the surrounding environments. CNE points out in its report of June 2009 that it seems quite unlikely to improve the efficiency of water processing such as it is currently practiced in each of the processing stations. However, this processing poses the problem of introducing foreign chemical substances in the aquatic environment (barium, aluminium). **AREVA should submit an evaluation of the current water processing practices for the end of 2011.** Within this context, Areva should take into account all the chemical and radiological risks, the current water processing practices and the associated liquid discharges (aluminium, barium, radium, uranium). Areva should also fix a timetable for its research on alternative processes. In addition, since the tagging of the sediments is linked to the quantities of uranium and radium emitted in the hydrographic network after processing, Areva should describe the relationship between the discharged flows and the accumulation of tagged sediments in rivers and especially in lakes, notably through a study of the speciation of uranium in water and the fine radiological characterisation of the sediments according to their grain size distribution and the hydraulic regime of the waterways.

The mining waste rocks

The waste rocks from old uranium mines contain radioactive elements with variable and sometime significant contents. The reuse of these waste rocks in the environment can lead over the years to the result that the use of the soil is incompatible with the presence of such waste rocks (for example, in the case of habitations constructed directly on such backfill). Without systematically reconsidering a priori past utilisations, it is important to make an inventory of the sites where waste rocks were reused with significantly higher levels of radioactivity than the natural background and to check the compatibility of the uses directly above and in the immediate environment of the zones where waste rocks were used.

In conformity with the circular of 22 July 2009 and the letter addressed on 12 July 2009 by AREVA's Chairwoman to the Minister of State, **such an inventory is going to be made and reported by AREVA (for the end of 2011), and situations of incompatibility will be identified and managed.**

As requested by ASN, AREVA adapted the evaluation methodology of the long-term dosimetric impact of the mining residues disposals to the case of the reusage of waste rocks. This study deserves to be completed for the end of 2011 so that the decision-making criteria retained by Areva for the various scenarios are sufficiently encompassing.

Areva may also apply by the end of 2011 its long-term impact evaluation methodology to the case of sterile lodes. To this end, it may be necessary to review the radon transfer modelling hypotheses from the lode containing the selectivity waste rocks to the habitation assumed to be constructed directly above for this type of scenario.

The CNE report of June 2009 stipulates that the waste rocks used in the coverings or the lodes hardly evolve chemically and that campaigns to characterise and measure the water which leaches the waste rocks are underway. **Areva should correlate its results with the geochemical models which it will have developed for the mining residues disposals by the end of 2012.**

3.4.2. Waste with enhanced natural radioactivity

As a result of the analysis of the characteristics inventory and the origin of the waste with enhanced natural radioactivity, as well as the management routes implemented for the management of this waste, ASN issued several recommendations in the report which it submitted to the Ministers :

- complete the inventory of waste with enhanced natural radioactivity by updating the ministerial order of 25 May 2005 and the BASIAS database for past industrial activities ;
- examine the modalities to reinforce the traceability of the waste with enhanced natural radioactivity ;
- make sure that there is no environmental impact from the historical disposals of waste with enhanced natural radioactivity and, if necessary, implement adapted environmental monitoring programmes ;
- propose actions to consolidate current processes to eliminate waste with enhanced natural radioactivity.

The following actions might be engaged as top-priority actions :

- **The services of the Minister of Ecology will conduct in connection with the concerned industrialists, the disposal centre managers and Andra for the end of 2011 an assessment of the application of the circular of 25 July 2006 related to the acceptance of waste with enhanced natural radioactivity in the waste disposal centres and will propose, if necessary, complementary actions to be implemented to secure and optimise the disposal of waste with enhanced natural radioactivity ;**

- **The concerned industrialists will draw up for the end of 2011 an inventory of the management routes to recover the mining residues containing enhanced natural radioactivity ;**

- **Andra will study by the end of 2012 within the framework of its waste storage projects the supply of storage solutions to industrialists producing occasionally waste with enhanced natural radioactivity which will be disposed of in the future LL-LL waste disposal centre.**

The application of the circular of 18 June 2009 related to the implementation of the High Committee for Transparency and Information on Nuclear Safety's (HCTISN) recommendations on nuclear safety should be pursued in order to ensure that the retained environmental monitoring provisions around the old disposals of waste containing enhanced natural radioactivity are adequate.

Moreover, provisions which aim at securing the funding for the management of waste with enhanced natural radioactivity at levels of radioactivity justifying its disposal in the future LL-LL waste disposal centre and internal dumps which can justify the set up of long-term monitoring provisions should be made.

3.4.3. Waste containing a radiological activity disposed of in conventional disposal centres

The dumps which accommodate waste containing a radiological activity originating from industry (nuclear or not) are listed in the Andra inventory 2009 without it being really possible to guarantee the exhaustiveness of such an inventory. However, considering the nature of these disposals and the concerned waste, the risks in terms of radiological protection seem mostly to be rather limited. However, it may be considered worthwhile to verify, particularly on the occasion of complements to be added to the inventory of the sites, that the environment is not radiologically tagged. In particular, it seems interesting to try to harmonise the radiological monitoring of the various disposal centres in which the low level radioactive waste was disposed of in the past and, if necessary, implement monitoring measures for deprived sites. The required monitoring level must be proportionate to the activities and the volumes disposed of. A record of the presence of this waste must be preserved. The High Committee for Transparency and Information on Nuclear Safety (HCTISN) in its recommendation[25] of 7 November 2008 on the radioecological follow-up of the water around nuclear facilities and the management of old storage sites of radioactive waste recommends *″ favouring knowledge about the taggings″* and recommends that *″the information about the monitoring of the underground water of the INBs, INBSs and sites where waste was stored concerns chemical as well as radiological substances″.*

The Ministry of the Ecology in its circular of 18 June 2009 related to the implementation of the recommendations of the High Committee for Transparency and Information on Nuclear Safety insists on making sure that the environmental monitoring is adapted on radioactive waste disposal or storage sites (except INB) and that, if necessary, on taking the appropriate measures (notably by targeted measurement campaigns).

Verifying the exhaustiveness of the inventory, as well as the study on the necessity of implementing radiological monitoring measures on the sites accommodating low level waste in the past, will be covered by an administrative action by the end of 2011 ; the radiological measures to be made will take into account the possible ways of transferring the various radioelements present in the disposals to the environment.

The Comurhex plant of Pierrelatte is the origin of liquid sub-products, which are processed to recover the uranium and the fluorine. The effluents are processed with lime (CaO_2) ; the fluorine precipitates out as calcium fluoride (CaF_2), a chemically stable compound found in the natural state as well. These fluorines have very low activity levels (on the order of 4Bq/g). These fluorines are stored in the dangerous waste disposal centre of Bellegarde. Stabilisation tests on the fluorines originating from the structures of the Comurhex facility implementing recycled uranium were performed for a possible disposal at Andra**. A solution for the management route of this waste satisfying technical and regulatory plans should be implemented by 2012.**

25 The HCTSIN recommendation is available at the following address : www.hctisn.fr

3.5. Long-term waste management : the new routes

Some research and development actions should be taken transversally to the various disposal and storage projects, notably in the modelling and simulation field (for example, finalise the development of the "Alliances" platform, allowing the analysis and the simulation of phenomena to be taken into account in the studies on the storage and disposal of radioactive waste). In addition, to improve knowledge and work upstream on the conditioning of the waste, research programmes on the following types of waste will be pursued (cf. 2.5) :

- the waste conditioned via the industrial management of spent fuel, such as it is practiced at La Hague ;
- the so-called "historical" waste stored at Marcoule and at La Hague during the industrial processing of spent fuel before the start-up of the UP3 plant (1990) or that from research activities from the same period ;
- the radium-bearing waste ;
- the graphite waste ;
- the waste originating from cleaning operations resulting from shutdown and that originating from the various deconstruction phases of the facilities ;
- the fuels from nuclear propulsion[26] and research reactors.

3.5.1. Solutions to be implemented for waste containing tritium

The storage of tritium-bearing waste without a management route concerns all the solid tritium-bearing waste already produced and to be produced until around 2060. The inventory of the concerned waste developed in section 2.5.1 of this report consists of six waste families for which the targeted objective is to ensure a reliable storage for a period of fifty years prior to its disposal in the Andra centres. The creation of new storage modules over a duration of fifty years offers a concrete solution ensuring the short- and medium-term safety in the management of tritium-bearing waste pending its accommodation in adapted outlets. The new storages that CEA should construct for the storage of its own waste will satisfy the principles defined in its orientation report. **CEA will communicate at the end of 2011 a progress memo on its storage creation programme.**

At the end of the first storage period, the waste could either be directed to a future Andra outlet, or remain in the initial storage site to extend the decay, or be directed to another storage site which will correspond to the safety requirements of the moment. By that time, the disposal centres should be dimensioned to accommodate this waste after the decay of tritium. However, for the sake of precaution, CEA should anticipate what will be the storage capacity needs for tritium-bearing waste, by examining possible alternative solutions if the disposals which should receive it after the fifty years of storage are unable to accommodate it. **To this end, CEA should examine for the end of 2011 the incidence of an increase in the storage duration on the design of the facilities.**

For irradiating waste which will be produced during the operation and dismantling of the ITER facility, the options retained for the management of this waste, as well as the associated timetables to implement them, should be prescribed at the appropriate moment. **ITER Organization and French authorities will periodically inform the working group responsible for elaborating the PNGMDR about the tritium-bearing waste management routes which it intends to retain.**

The CEA orientation report does not present any provisions in terms of waste recovery ; the design criteria linked to the maintenance of the storage (interventions on packages and equipment, maintaining the confinement barriers in condition, etc.) are not prescribed. **It seems important that the main principles concerning the recovery of packages under satisfactory safety conditions be known as rapidly as possible, since the possibility of recovering the stored waste packages at any moment under satisfactory safety conditions is one of the fundamentals in the design of storage facilities. CEA should complete its report in this field for the end of 2011.**

[26] Since the option of processing these fuels in the plant at La Hague is still under study, they are considered and declared to be reusable materials, but are included in the R&D programmes for the long-term management of HL/IL-LL waste as a prevention measure.

Considering the difficulty of confining tritium, the new storages will contribute to the significant increase of tritium discharges in some facilities. Also, CEA will examine the feasibility of reducing as much as possible tritium discharges for storages whose discharges are the highest.

The management modalities for tritium-bearing waste originating from the diffused nuclear producers vary and are sometimes inappropriate. Moreover, there exist major uncertainities about the quantity of waste liable to be produced with highly varied activities in the diffused nuclear sector. Finally, for the liquid and gaseous tritium-bearing waste currently without any elimination management route and not covered by the study submitted by CEA, specific processings to eliminate it are to be provided for in the short term.

As a result :

- **Andra in conjunction with CEA will propose by the end of 2010 modalities to take care of the tritium-bearing waste originating from the diffused nuclear sector and whose inventory is already known in decay storages.**

- **Andra in conjunction with the concerned holders shall draw up for the end of 2011 an exhaustive inventory of the tritium-bearing waste originating from the diffused nuclear sector, notably taking into account the radioactive objects and the sealed radioactive sources present in civil equipment (aeronautics, railway, etc.) and in defence, and identify in conjunction with CEA whether the consolidated inventory could lead to a reconsideration of the principles of accommodating the waste from the diffused nuclear sector in decay storages defined at the end of 2010 (see above).**

- **ANDRA shall submit for the end of 2011 a study specifying the specific processings to be implemented for the elimination of the tritium-bearing waste originating from the diffused nuclear sector in the liquid and gaseous states currently without any management route (including** disused **sealed gaseous radioactive sources containing tritium).**

3.5.2. Solutions to be implemented for disused sealed radioactive sources

The inventory of disused **sealed radioactive sources drawn up by Andra is relevant and the acceptance criteria retained by Andra allow orienting the considered sources to the various possible disposal solutions,** which can be considered to be a notable breakthrough compared to the previous PNGMDR.

Firstly, it should be noted that the disused sealed radioactive sources are potentially reusable. The IAEA control guide indicates notably that ″each State should encourage the reuse or the recycling of radioactive sources whenever possible and conform to the safety and security principles″. In the remainder of the text and in accordance with the goal of the PNGMDR, the disused sealed radioactive sources will be essentially focused on after a decision has been made to manage them as waste. As a general rule, this decision is to be conformed to by a supplier of sources after they have been recovered from users, or by any other authorised manager of a recovery management route for disused sealed radioactive sources (and notably Andra).

This inventory of the sources to be disposed of should be periodically re-evaluated, but it is highly unlikely that the uncertainties weighing on the completed inventory will call for a reconsideration of the capacity to accommodate disused sealed radioactive sources in the various envisioned disposal solutions.

The detailed inventory of the disused **sealed radioactive sources drawn up by Andra should be systematically updated with the French sealed radioactive sources when they are declared worn out to IRSN, since the IRSN is in charge of the inventory of sealed radioactive sources. The modalities for the implementation of this provision will be studied by Andra and IRSN by the end of 2011.**

Moreover, the IAEA control guide indicates that ″each State should authorise the return on its territory of radioactive sources withdrawn from service if, according to its domestic law, it has accepted that they be re-shipped to an authorised manufacturer″. In practice, many countries have national management routes, but some holders of sources supplied by French manufacturers of sources or equipment demand the return to France of their sources ; therefore, flows should be small, but can be late because the ten-year source utilisation limitation requirement is specific to French regulations and hence not applicable to sources used abroad.

The management of disused sealed radioactive sources must take into account, in particular, their activity and their volume and be such that it preserves for each type of disposal the radiological capacity to allow the elimination of the waste for which these disposals are more specifically designed. **The Andra study presents only partially the global estimation of the activities and volumes of the sealed radioactive sources which would be oriented to each of the provided disposals. Andra should complete its inventory on these values by the end of 2011.** The source holders will supply the necessary information to Andra by the end of 2010.

For the orientation of the disused sealed radioactive sources in the various disposal solutions, the criteria retained for this purpose (source's physical condition, radionuclide's half-life, the source's activity and its size, disposal packages's activity and the disposal packages' thermal power) offer a global vision of the constraints specific to the disposals for the management of the various disused sealed radioactive sources which their holder intends to discard as waste**.** These management criteria can be used by holders of stocks of disused sealed radioactive sources recovered and intended to be managed as waste as a basis for the elaboration of a management strategy of the various lots of disused sealed radioactive sources taking into account the possible elimination management routes. This will allow having a global vision on the management of the disused sources, their recovery or collection, up to their disposal. **The study presented by Andra establishes, therefore, an initial master plan for the orientation and elimination of** disused **sealed radioactive sources, which should be completed and amended by taking into account the constraints of the holders of** disused **sources recovered and intended to be disposed of.**

For the management route identification method, the principle of addressing to the disposal centre accommodating very low radioactive waste (VLLDC of Morvilliers) very low level sources and reserving the management route of the deep geological repository or the LL-LL disposal to, respectively, long lived sources of high level activity (deep geological repository) or low level activity (LL-LL disposal) in line with the criteria retained by Andra seems acceptable.

Moreover, the disposal of the disused sealed radioactive sources in facilities where they are protected from ordinary human intrusions for the time it takes them to no longer be of a significant radiological risk must be retained as a key principle for their elimination. Thus, even though margins were taken by Andra to account for uncertainties which affect the determination of the SAL, the surface centres or the sub-surface centres at a depth on the order of 15 metres remain insufficiently robust for the sealed radioactive sources to protect against long-term risks of intrusion and therefore should not accommodate sources whose residual activity remains significant after a few hundred years have elapsed, except if this solution offers a true benefit for the safety of their global management. In any case, considering the small volume that the sources to be disposed of represent, the disposal of all the sealed radioactive sources (except for those of very low activity or a short half-life : notably, the sources with a half-life less than or equal to that of cobalt 60 not necessitating the definition of a SAL) in a HL/IL-LL or LL-LL centre should be privileged whenever possible. Pending the opening of these management routes, these sources could be stored under safe conditions notably in the new facilities intended to take over from the old storages.

The reflection of Andra and the source holders should be pursued to optimise the master plan for the management of disused sealed radioactive sources and integrate better the national inventory of the sealed radioactive sources to be eliminated, as well as the short- and medium-term safety throughout the management phases of these sources : availability of storages and existing disposals or those to be created, alternative management routes (reusage, recycling, etc.). **The following work orientations are retained :**

1. **The holders in concertation with Andra will study in depth for the end of 2011 the following points :**
   - **the processes for processing sealed liquid and gaseous radioactive sources in order to eliminate them ;**
   - **the study of conditioning processes adapted to the disposal management routes.**

2. **The holders of** disused **sealed radioactive sources will propose for the end of 2011 a "allotment" of the** disused **sealed radioactive sources which they have or expect to receive and which are intended to be managed as waste. In order to define each lot, the holders will take into account the considered elimination and disposal management route(s) in connection with Andra. If necessary, a complementary characterisation programme of these sources wil be defined to orient them to an elimination and disposal management route.**

3. **Andra will lead a working group uniting ASN, DSND, Andra, CEA, IRSN and the main holders or suppliers of sealed radioactive sources in order to propose for 2012 recommendations on the optimisation of the planning of the recoveries and collections of** disused **sealed radioactive sources, as well as their compatibility with the temporal availability of the conditioning, storage and disposal management routes.**

The system of financial guarantees designed to remedy the problem of defaulting suppliers of sources at the moment of their recovery must also be updated and completed, if necessary. Up to now, this guarantee was given by a mutualisation system backed by an association uniting a large part of the source suppliers (Resources Association) or by an agreement system with Andra (a deposit guarantee with Andra). The impact of the orientations retained by the PNGMDR on the current guarantees with Andra will have to be examined for suppliers who do not desire or cannot adhere to the Resources Assocation. **A working group will be set up associating Resources, Andra, the users and the suppliers of sources, and ASN for the purpose of elaborating a proposal in this sense by the end of 2011.**

For the disused sealed liquid and gaseous radioactive sources which cannot be disposed of as is, the processing solutions (gaseous sources with ^{85}Kr in surge absorbers) or a storage (case of gaseous tritium-bearing sources) are sketched out by Andra. The holders of such sources should now develop adapted processing solutions before their disposal.

In addition to the above main actions, actions specific to certain types of sources are to be taken.

Sources containing tritium

Disused sealed radioactive sources containing solid tritium were and will be taken into account in the study of the storage of tritium-bearing waste without any management route (see section 2.5). At the end of this storage, they may be disposed of in the LL/IL-SL management route. Gaseous tritium-bearing sources (light bulbs, etc.) may be stored until their activity becomes compatible with the acceptance threshold in the LL/IL-SL management route. For the disposal, these spent sources should be immobilised by a hydraulic binder. This immobilisation before the storage is liable to reduce degassing in the storage phase. As an extension of the study of the storage of the tritium-bearing waste without any management route, CEA will evaluate and compare the immobilisation possibilities before and after storage in terms of environmental and technico-economic impact.

Other liquid or gaseous sources

Other spent liquid sources (Co^{60}, Ra^{226}, Cs^{137}, etc.) and gaseous sources (Kr^{85}, etc.) are not designed as is for a disposal management route. The sealed liquid radioactive sources could be opened to process their content like effluents. Likewise, gaseous sources could also be opened either to reuse the material (case of Kr^{85}) or to eliminate it within the framework of controlled discharges (or for dissolving). The processing of spent liquid and gaseous sources should be considered by their holders in facilities to be identified which are equipped with suitable means for handling (ventilated hood, glove box) and processing the effluents and discharges.

Sources containing cobalt 60

The disposal of sources containing cobalt 60 at LL/ILDC raises the question of what type of container to use. An option considered by CEA (for CEA and CIS Bio International sources) is a disposal in a shielded shipping cask ; it offers the advantage of simplifying the radiological protection for all the operations. However, this option would lead to the disposal of chemical toxics at LL/ILDC. Also, CEA will study complementary management options which could eventually replace the current management route taking into account the recovery and conditioning calendar for these sources. In addition, CEA and Andra will work together in concert to optimise the efficiency of the current management route.

Sources containing cesium chloride

In the most active sources, cesium 137 is in the form of a powdered soluble chloride. CEA will give top priority to examining the possibilities of reusing the cesium.

Lightning rod sources

Because of the large number of radioactive lightning rods still to be collected, ways should be sought to optimise the transport, dismounting and conditioning phases. Thus, Andra should undertake a process study to separate in a better way the sources from the lightning rod heads and the collection process waste, densify the drums and optimise the storage and disposal conditions and volumes. Ideally, such a process is to implemented on a collection and processing site. It would be applied to lightning rods containing radium 226, mixed and americium 241. **CEA will examine with Andra the feasibility and the interest of adopting a conditioning management route for radium-bearing lightning rods and a conditioning management route for fire detector sources (without a prior compacting phase).**

3.5.3. The LL-LL project : graphite, radium-bearing and other waste

Note : The timetables for the LL-LL project will be subsequently prescribed.

Knowledge about and conditioning of LL-LL waste

The quantitative inventory and characterisation work on all the waste intended for the shallow depth disposal will be studied in depth. In particular, **Andra will propose to the Government a dimensioning inventory model of the disposal centre.**

In addition, studies on the knowledge, behavour and processing of the LL-LL waste should be pursued.

For radium-bearing waste, the analysis of the speciation of the radionuclides, as well as the effects of complexing agents and waste salts on the transfer of the radionuclides will be studied in depth ; also, the oxidation – reduction conditions within the disposal and its geological environment (in particular, the disposal under a recast covering (SCR)) should be controlled and the relevant parameters determined in order to minimise any possible impact from chemical toxics. Moreover, Andra and the concerned waste producers (notably Rhodia) will examine the interest and the modalities of a possible separation of the nitrates.

In the case of graphite waste, studies will be conducted, in particular, on chlorine 36 and carbon 14 in order to devise an initial model covering the release of radionuclides by graphite for the preparatory calculations for the DAC and to detail the inventory in chlorine 36. In addition, EDF and CEA will submit an updated summary report about the R&D accomplished in France and abroad on the graphite waste processing solutions and especially on the possibilities of thermal processing, the characteristics of the waste and the induced effluents and the potential processings to be applied to them, as well as their industrial perspectives.

Studies should also be pursued by the end of 2010 concerning the possibility of accommodating certain bituminised waste in the disposal for low level and long lived waste : phenomenological analysis, nuclide release and migration simulations, and adaptation study of the disposal's architecture and the operation means.

In addition, it is important that the LL-LL waste conditioning specifications be known as soon as possible so that the waste producers can set up the corresponding conditioning solutions. These specifications will depend, however, on the results of the studies to be conducted in the future by Andra according to the finally retained concepts and sites ; therefore, it is not possible to define today all the waste package design parameters. On the other hand, il would be desirable to set as soon as possible the parameters which are not very likely to evolve. As a result, **Andra and the LL-LL waste producers will organise a working group to determine a timetable for defining the main parameters for the LL-LL waste conditioning choice during the three years preceding the disposal creation authorisation application.**

Selecting a disposal site : geological studies and concertation process

The Government and Andra are currently examining the adaptations to be made to the request for quotes process and the calendar of the project. **The search for a site will be pursued based on the remaining candidature applications still open, while taking the time for concertation, respecting the principle of free choice for the French communities and according all their importance to the geological parameters.**

Once the sites are pre-selected, Andra will perform in-depth environmental and geological investigations and will pursue its approach to promote information and a dialogue on the project. An approach follow-up committee will be set up at the local level to ensure transparency and concertation. The coordination of the proposals related to sponsoring and to the elaboration of the territorial projects will be ensured by the prefect of the department.

The site exploration resources implemented from the surface will allow accessing the data specific to the sites (topography, geological section, geotechnical and hydrogeological characteristics of the formations, etc.), as well as the samples necessary for the characterisation of the physico-chemical properties.

Knowledge about the geological context should allow determining the available volume of the potential host formation as well as some of its properties, such as its capacity to delay the migration of radionuclides or its ability to create the disposal infrastructures. The surroundings of the host layer will also be characterised in order to construct a hydrogeological scheme and contribute to the building of an overall geological model.

On these bases, the studies on the natural evolution of the geological medium must respond to three key objectives for the evaluations of safety :

- analyse the risk of an erosion of the disposal (in particular, SCR) ;
- estimate the modifications of the underlying surroundings, such as the creation or the development of karsts ;
- characterise the physical components of the typical biospheres possible in the future.

A public debate will be organised at a date to be subsequently prescribed. To this end, Andra will create a report to support the public debate including notably a site choice proposal.

3.5.4. Research on HL/IL-LL waste : separation / transmutation, reversible geological disposal, storage

Research in the separation-transmutation field

Recall that the previous PNGMDR had fixed a number of milestones for research on separation and transmutation and they remain valid.

Thus, **CEA should submit before the end of 2012 a report providing an assessment of the research. This report will include the technical advancements made in the fields concerning the processing and separation processes, the fabrication of fuels with minor actinides and the irradiation experiences on these fuels.** It will deal with complete processes going from the separation phase up to transmutation in the reactor through the fuel fabrication phase.

The report will also include the results from technical and economic scenarios taking into account the optimisation possibilities between the transmutation processes of the HL-LL waste, its storage and its disposal in a geological formation. It will allow evaluating (a) the contribution of the recycling of the minor actinides and their transmutation with respect to their disposal within the vitrified waste ; (b) the various imaginable recycling methods (heterogeneous, homogeneous) ; and (c) the possible associated management routes (critical new generation nuclear power reactors, accelerator driven subcritical reactors).

This report should allow proceeding to an evaluation of the industrial perspectives of these management routes and making choices concerning the new generation reactor prototype whose entry in operation is scheduled for the end of 2020. It will take into account the orientations retained abroad in terms of techniques, as well as in terms of the evolution of the installed electric bases and industrial strategy of the main players.

The part of the report devoted to the processing and fabrication of fuel with minor actinides will be coordinated with the work on the new generation reactors and accelerator driven reactors.

CEA will rely on Andra to evaluate the impact of the waste composition on the disposal's dimensioning and cost. It will participate in international cooperation programmes and notably European research programmes.

Technico-economic studies will allow having by 2012 cost evaluation items for the implementation of the various transmutation options studied at the scale of the installed electronuclear base. They will also allow evaluating the consequences of the implementation of these options on the deployment of the 4th generation reactors (notably in terms of required resources), the capacities of the cycle's facilities, the produced waste and its surface surface on the geological disposal, as well as the associated economic impacts. The contributions of these various options and then detriments will be presented, as well as the various possible deployment scenarios. These studies are conducted by CEA in conjunction with the industrialists in order to notably define the choice of the studied scenarios, the optimisation parameters and the evaluation criteria.

In order to establish the aforementioned report, the research in the field of separation will be essentially pursued in three fields :

- recovery by adapting and making complements to the PUREX process (or COEX process) of the neptunium, americium and curium present in the spent fuel [extensive separation – DIAMEX-SANEX processes] ;
- recovery downstream from COEX or PUREX of only americium (the main contributor to radio-toxicity and long-term thermal power of today's glasses) ;
- global recovery of all the transuranians (plutonium and minor actinides) [grouped separation – GANEX process].

A special effort will be made on the second point (separation of only americium) in agreement with the CNE's recommendations.

In addition, with a view of an industrial transposition, the R&D studies will be pursued in order to simplify the schemes (notably by reducing the number of successive elementary phases and by seeking higher concentrations) and to acquire the consolidations required for their implementation (more closely approaching in their various dimensions the industrial implementation conditions of these processes).

The studies on separation will be completed by more prospecting research on the pyrochemical processes, which offer assets for the processing of fuels hardly soluble in the aqueous phase and which would allow processing very radioactive fuels as soon as they are unloaded from the reactor (for example, fuels intended for ADS). Thus, it will be necessary to strive to conduct at the laboratory scale a first series of experiments on an irradiated object around 2012.

After the separation phase of the elements to be transmuted, the actinides conversion phases are necessary before the fabrication of the fuel in order to obtain a solid compound from the nitric solutions of actinides originating from the separation processes. The R&D programmes will be pursued by 2012 to evaluate the various ways of converting the solutions loaded with minor actinides in order to identify the advantages and disadvantages of each of them. In particular, the development of the U-Pu co-conversion up to an industrial stage and the adaptation of the fabrication phases from the fuel ceramic to the new powder type will be studied. In addition, demonstrating the technological feasibility of transmutation necessitates having access to experimental fuel fabrication tools : the feasibility and the cost for the construction of a pilot facility for the fabrication of fuels loaded with minor actinides for experiments at the needle scale (the ALFA project) will be studied ; AREVA and CEA will jointly evaluate the feasibility and the cost of the construction on the site of La Hague of a MOX fuel fabrication workshop for the ASTRID fast neutron reactor prototype.

To evaluate the feasibility of the various transmutation options, which today do not all have the same level of maturity, it is necessary to consider various factors, such as the fabrication of the materials, the handling of the fuels, targets or coverings, the impact on the reactor, the behavour under irradiation and its modelling, and finally the processing of the irradiated material :

- Recycling of the minor actinides in the homogenous mode : the minor actinides are incorporated in the fuel in small proportions, so that the impact on the core's safety parameters remains limited (typically a few percent). Since it is the most mature option, the next stage will be to demonstrate the feasibility at the scale of several needles, which could be done abroad or else directly in the French prototype ASTRID.
- Recycling of the minor actinides in the heterogeneous mode : the minor actinides are this time concentrated in dedicated assemblies generally positioned around the core's periphery and, on account of this, have little impact on the core's safety parameters. Two approaches are considered :
  - recycling on an inert medium : many studies have already been done, but will necessitate new experiments to consolidate the feasibility ;
  - Coverings Loaded with Minor actinides (CCAM) : this approach seems attractive and has been given priority to be explored by the National Evaluation Committee (CNE) ; a concerted effort will be made on this topic, notably to have elements related to the transmutation performances, the impact on the cycle and the reactor's safety, in parallel with the preparation of experiments ;
- Recycling in a dedicated ADS reactor : the minor actinides are concentrated in the ADS fuel (typically 50%) and are then associated with plutonium. Irradiations will go on in order to make in 2012 a first feasibility evaluation of the ADS fuel.

As indicated, one of the possible approaches for the transmutation of the minor actinides relies on the utilisation of 4th generation reactors. The fine-tunings of these reactors had been scheduled by the Atomic Energy Committees for 20 December 2006 and 20 May 2008. After a consolidation in 2009, a feasibility review in 2012 should allow making an assessment with a view of choosing the gas management route and the sodium management route (with four main elements in the 2012 report : safety, savings, cycle, industrial perspectives).

In the medium and long term, the deployment of the 4th generation reactors will necessitate the reprocessing of the MOX fuels at a greater scale, which will have consequences to be anticipated on waste production (notably increase in minor actinides). The fuel cycle associated with the 4th generation reactors should be defined with the objective of reducing the quantities, the thermal load and the radiotoxicity of the waste by anticipating the possible necessary evolutions of the waste management routes. Finally, in the perspective of an eventual construction of new reprocessing–recycling plants far from the sea, trapping and conditioning of certain volatile fission products such as iodine will be examined.

Finally, separation-transmutation necessitates upstream research in the nuclear data field. A hierarchical list was drawn up for the isotopes (with the isotopes of americium and plutonium at the top of the list) and the efficient cross sections (fission, capture, reaction, nonelastic, total) for which the current data are considered to lack precision or else are simply missing. These acquired differential data may be used in the most recent simulation tools for a revisit of the results available from integral experiments in the fast reactor. Even though the covered energy field is mostly that of critical thermal and fast reactors, a fraction of the work programme will also cover the relevant efficient cross sections (essentially cladding materials) for the highest energies encountered in the ADSs.

Research on the reversible disposal in a deep geological layer

The previous PNGMDR had also set the milestones for research on the reversible disposal in a deep geological layer. Thus, Andra had to propose by the end of 2009 (a) a zone of interest for depth exploration of limited size (ZIRA) favourable for the installation of a disposal on which deep exploration techniques will be implemented ; (b) design, operational and long-term safety, and reversibility options; (c) an inventory model of the waste to be taken into account ; and (d) storage options as a complement to disposal options. Some of these elements have already been presented in section 2.5.4, in particular, the zone of interest of limited size and the inventory model**.**

At the end of 2012, Andra should submit the report to support the organisation of the public debate which will take place before an authorisation application is filed for the creation of a deep geological repository site. In addition, Andra is scheduled to file the authorisation application for the creation of a deep geological repository site at the end of 2014 for entry in operation in 2025.

After validation of the zone of interest for depth exploration (ZIRA) on the order of 30 km^2, and in order to prepare the installation of the disposal, exploration resources will be implemented as of 2010 to allow defining with precision the geometry of the geological layers, their layout and the properties of the rock composing them. The acquisition and processing of high-resolution 3D seismic data will aim at, in particular, reinforcing the interpretations on the structurisation of the sedimentary stack, ensuring there are no tectonic structures in the Callovo-Oxfordian layer, and having a 3D vision of the distribution of certain properties of the layer and its surroundings. At this stage, a 3D geometric modelling of the layer will be available which will provide the necessary framework to propose more precise installation choices for the disposal.

The observation of the surface environment will aim at not only supplying regulatory data for the initial condition of the site, but also understanding the dynamics of the media for the impact study and the dimensioning of the environment monitoring during the construction and operation of the disposal. The Observatoire Pérenne de l'environnement (OPE – Perenne Observatory for the Environment) aims notably at coping with the issues linked to the duration of the observation/monitoring duration of the disposal. It envisions, in particular, data management and a preservation of the samples to keep a record of the reference situation through the installation around 2012 of an eco-library on the Meuse/Haute-Marne site.

The observation and monitoring of the structures, in particular, those of the cells, should allow following their phenomenological evolution and provide knowledge to support the management of a reversible disposal. It amounts to being able to re-evaluate the lifetime of the structures and providing the elements required to evaluate the possible removal conditions of the disposal packages. In this context, the selected measurement resources must take into account the specific constraints of a disposal, such as discretion (miniaturisation, wireless communication) and robustness (sustainability in a hostile environment, autonomy). R&D actions will thus be necessary for the measurement resources ; a part will be accomplished within the framework of the European monitoring project ″MoDeRn″, which is part of the 7th PCRD, with Andra as the coordinator.

The demonstration testing and experimentation programme in the underground research laboratory defines the priorities to satisfy the needs of the HL/IL-LL project and integrates the development possibilities for the laboratory's architecture offered by the renewal of the laboratory's authorisation beyond 2011. In particular, the following objectives shall be retained : enhanced knowledge of elementary phenomena (notably thermohydromechanical behaviours, desaturation - saturation and gas transfer ; interactions between disposal materials and argilites) ; fine-tuning of the digging method for HL waste disposal cells ; digging tests with the road header and non-arched ground supports ; preparatory testing for the drift seal test, making the seal.

Research will also be conducted to support the safety appraisal of the deep geological repository : IRSN organised itself to produce on time the appraisals of the safety files which will be presented by

Andra for the creation of new disposal facilities for radioactive waste, notably the deep geological repository. The position of the IRSN research activities on this topic differ from that of Andra ; mobilising much more limited means, these activities are focused on a restricted number of targeted topics aimed at independently providing the support needed for the appraisals to come. IRSN is planning during the period 2009-2012 to explore more particularly the following fields : major characteristics for the confinement capacity of the geological barrier (in particular, for the site studied by Andra) ; thermo-hydro-mechanical phenomena liable to affect the performances of the disposal components (notably the creation process of the fractured zone around the structures during their digging or EDZ), main physico-chemical evolution factors of the disposal components, and global modelling of the disposal. IRSN will continue to conduct its research in cooperation with other scientific partners and make available its experimental means to its network of partners, especially the experimental station in the clayey medium of Tournemire in the Aveyron department.

Finally, research in the human and social sciences will be pursued, particularly in the field of reversibility. Based on a study day organised around this topic on 2 October 2008, Andra scheduled an interdisciplinary colloquium in June 2009. By extending reflections to other fields (GMOs, nanotechnologies, climatic reheating, etc.) and other comparable industrial experiments, it is planned to publish a reference work on the issue. The colloquium of June 2009 prefigures, in addition, the international colloquium of the NEA/OECD scheduled for 2010. Andra would like to consolidate this community of interest between the HSS and the Agency around reversibility before extending the list of thematics to be treated and the possibilities of collaboration. It is already envisioned to deal with the issue of the preservation of the memory of the sites in the same spirit as of 2009-2010.

Research on the storage of HL/IL-LL waste

The previous PNGMDR provides for Andra submitting at the latest by the end of 2009 to the Ministers of Energy, Research and the Environment the programme of studies which it proposes to conduct on the possible evolutions in terms of storage of HL and IL-LL waste.

Studies of the scenarios storage-transport-disposal scenarios identified in sections 2.1.2 and 3.1.2 will help in drawing up the list of storage needs : families and forms[27] of packages to be stored, necessary capacities, target availability dates and operation durations. These studies will aim at an overal optimisation of the management routes, with respect to safety, environmental impact and cost. They will take into account the disposal's reversibility, notably by systematically identifying the storage solutions for accommodating the packages which would be removed from the disposal.

Research for the design of the storage facilities will be essentially oriented toward the behaviour of the materials used to construct the storage structures and, to a lesser extent, toward the behaviour of the packaging materials : study of the carbonation of the cement materials, evaluation of the creep in concretes at high temperature, studies on gaseous and aqueous transfers in unsaturated cement materials, documentary analysis of the corrosion of metallic materials under radiation, creation of an atmospheric corrosion model, etc.

In addition, by 2012, Andra will lead along with the waste producers studies on the technical concepts to (i) deepen innovative solutions reinforcing the storage-disposal complementarity, solutions which will be applicable to all future storage facility projects, (ii) design storage facilities which could be integrated in the deep geological repository for the various imaginable waste package management scenarios (see section 3.1.2). These studies will cover the engineering of the facilities, their behaviour and their phenomenological evolution over a century, and their safety. They will be conducted especially to favour the complementarity between, on the one hand, the ″system″ consisting of current and future storage facilities on the various sites and, on the other hand, the disposal by taking into consideration the control facilities of the primary packages, conditioning in a disposal container and the transports. The studies and research will also aim at reinforcing the sustainability of future storage facilities over a century, and increasing their universality with respect to the waste packages to be accommodated in them.

[27] The form can correspond to the primary package, such as described in the national inventory, or to the disposal package.

Andra will receive and capitalise on the feedback coming from the construction and operation of the existing facilities or those under development. It will offer technical support to the operators to favour the complementarity of their creation or extension projects with the disposal. It will elaborate a recommendations guide for the design of storage facilities in keeping with this complementarity.

Andra will submit at the end of 2012 an overall assessment of the studies and research on the storage which it will have led and coordinated (including studies concerning the HL/IL-LL waste mentioned in 3.1.2)**.** The proposals retained within the framework of the next revision of the PNGMDR, in addition to the transit capacities necessary for the disposal's operation, will be presented at the public debate on the disposal centre project. Depending on the results of the debate, these proposals may be included in the ″authorisation application for the creation of the centre″, or DAC, filed by Andra for an enquiry in 2015. The DAC file will take into account the time scheduling for when the storage capacities will become available.

Research on knowledge and conditioning of HL/IL-LL waste

Today, the reference industrial process for the conditioning of high level waste in France is vitrification. **Glass formulation studies will be pursued to take into account the evolutions in the compositions of the fission product solutions and treat other types of waste,** notably in relation with the placing in operation in 2010 of the ″cold crucible″ vitrification process in a vitrification line at La Hague**. In the longer term, for the sake of rationalisation, studies (process and materials) aimed at extending the field of application of the vitrification will be pursued for certain effluents**. For "current" glasses, to progressively enhance the realism and robustness of the glass behavioural models necessary for Andra to make the disposal studies, studies aimed at refining the knowledge of the alternation physico-chemical mechanisms will be conducted taking into account, in addition, the possibilities of evolution in the composition of the spent fuels (notably increased minor actinide contents). The studies will also aim at proposing less ″over-estimated″ models for the transfer of radionuclides outside the glass and within the corrosion products. This research will allow consolidating the behavioural models of the vitrified waste packages whose first version is expected for 2010 and the knowledge referentials expected for 2012.

For the IL-LL waste, within the framework of the work performed on orientation 3 of the Act of 30 December 1991, it was demonstrated that conditioning processes may be implemented for the various existing waste categories. The National Evaluation Committee retained that in this field industrial maturity had been obtained, but that many improvement lines still exist in terms of conditioning (notably for the ″historical″ waste). The research to be pursued is intended to explore and implement the improvement lines. **Studies on the knowledge and conditioning of the intermediate level waste will be pursued in order to (i) continue to reduce the volume of waste produced besides the objectives of reducing the waste at the source ; (ii) obtain a physico-chemical form of the most possibly inert waste, facilitating its subsequent conditioning ; and (iii) have conditioning methods to allow a better control of the produced waste packages, limiting the long-term and in-operation safety constraints of the disposal.**

More precisely, the major issues of the upcoming years concern :

- decontamination : for liquids, reduction of the quantities of reagents and chemical toxics in relation to the evolutions of regulations ; for solids, reduction of the quantities of generated effluents ;
- waste processing : in particular, development of processing pathways for waste containing organic matter, notably the technological waste (ion exchange resins, latex or neoprene gloves, other polymers, etc.) or effluents (organic solvents, surface-active solutions, etc.) ;
- waste conditioning : broadening of the field of waste that can be conditioned by cementation or vitrification, while preserving the assets in terms of cost and implementation ; formulation studies of concretes to condition liquid effluents (rich in sulphates or borates, etc.) or solids (waste originating from the uncladding of UNGG fuels, graphite waste, etc.).

Article 7 of the Act of 28 June 2006 specifies that the owners of IL-LL waste produced before 2015 must condition it at the latest in 2030. **In order to prepare for the disposal of this historical IL-LL waste, the producers are asked to present by the end of 2011 a memo on the advancement of the work which they will have conducted in conjunction with Andra to define the appropriate conditioning methods** ; the main problems still to be resolved will be identified and a first assessment of the envisioned solutions will be made**.**

Long-term behavioural studies on the IL-LL waste will continue to be conducted on three main thematics under the sub-groups of the Andra / CEA / Producers Technical Committee : bituminised sludge packages ; gases originating from the corrosion of metallic materials and radioactive gases ; organic waste (other than bituminised sludge). For concrete disposal packages, the R&D implemented within the group of laboratories engaged in the ″evaluation of cement structures″ will be pursued.

In particular, as indicated in 2.5.4, an R&D program was set up to improve the modelling tools for forecasting the production of hydrogen and to identify the productions of water soluble molecules, degradation products of polymers, liable to complex the radionuclides. It will lead notably to the creation of a database (PRELOG) on the intrinsic data related to the polymers which, in conjunction with the modelling, will allow evaluating the gas production yields from the main data on polymer composition and the radiation spectrum.

Andra will submit for the end of 2010 a report evaluating the impact on the disposal of the waste containing organic matter and irradiating materials or those rich in alpha-emitting elements, specifically with respect to the safety in the disposal.

For the waste containing organic matter, processings leading to the elimination or the reduction of the organic matter content in the waste would allow limiting the hydrogen produced by the transformation of this matter under the effect of radiolysis and would allow preventing the appearance of substances which might have a complexing nature, as well as the interactions with microorganisms. These processes reducing the organic content in the waste include notably the separation of flows upstream and hot or cold processing.

Based on this, the mineralisation by hot processes of long lived waste containing a significant organic quantity opens the way to promising technological progress, provided the technico-economic feasibility is refined. These techniques will be studied within the framework of IL-LL waste, but could possibly be extended to all the solutions.

Today, incineration allows processing some families of low or intermediate level and short lived organic waste and also processing some kinds of liquid waste not directly acceptable in the Andra disposal centres because of their physical state. A nuclearised incinerator CENTRACO is currently being operated by the SOCODEI Company at Marcoule. Taking into account the conditioning required for the management of the waste by Andra, the incinerated waste volume is reduced by a factor of 10 to 20. Incineration is a processing process well adapted to low or intermediate level and short lived waste containing lots of organic matter. The thus-treated waste is composed of, among others, the equipment of the interveners in the controlled zone (gloves, overshoes, work suits), but also liquid effluents (washing solutions, oils, solvents, concentrates), filters and resins originating from the nuclear facilities. Energy reusability from incineration remains marginal today, but would be an added value of the management solution. In some cases, incineration may allow denaturing hazardous components in order to avoid their reuse and potential attractiveness after the closing of the disposal.

For intermediate level and long lived waste, R&D is currently being conducted on a waste incineration process within a high temperature gas plasma (4500℃) generated by a torch. Current studies are also considering the direct incorporation in a molten glass bath (SHIVA process). The technique of plasma-induced destruction followed by a vitrification is already used for the destruction of some types of industrial waste, such as waste originating from the electronics industry. Studies aim at rendering this technique applicable to intermediate level and long lived waste. The work will be conducted notably on the nuclearisation of the entire technology. This initiative is limited by the investments which will be necessary and the operating costs which will climb with an exploitation in the nuclear field.

CEA and AREVA will present the assessments of the studies in this field at the end of 2011. These studies will be conducted to ensure the pre-development of the process, advance it to the industrial feasibility stage, and enable by 2020 to pronounce its deployment at the industrial scale. More generally, for waste containing a significant fraction of organic matter, the concerned producers will present at the end of 2011 imaginable processing-conditioning scenarios to allow notably limiting hydrogen production by taking into account the radiological protection, industrial and financial aspects, as well as a deliberated calendar implementing the envisioned process(es).

3.6. Improving the global consistency of the management of radioactive materials and waste

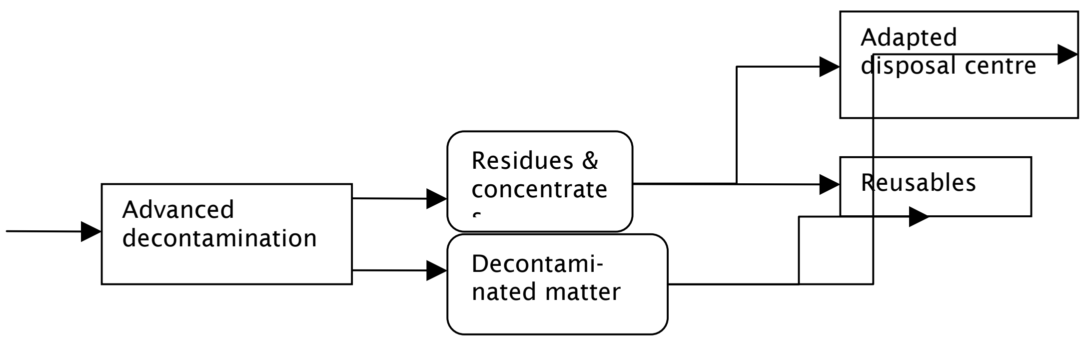
Three orientations are pursued in order to improve the global consistency of the management of radioactive materials and waste : the definition of management routes for waste categories still without any management route ; the optimisation of the distribution of waste between management routes existing today or in the project stage ; and research in the field of human and social sciences.

3.6.1. Defining management methods for waste categories currently without a management route

In section 2.6.1, a list is given of waste categories currently without a management route. **The nuclear operators and Andra will define by the end of 2011 management modalities adapted to the special physico-chemical features of this waste.** To do this, a working group led by DGEC and associating ASN will be set up. If necessary, R&D programmes needed for implementing these solutions will be described.

In particular, the implementation of advanced decontamination processes can be a very interesting solution in some cases where the radionuclides do not originate from the activation of the material. They allow recovering the reusable radioactive materials or concentrating the radionuclides for a specific management. The diffusion barriers of the Georges Besse plant are an example of an LL-LL waste which after advanced decontamination should have an activity compatible with VLLDC. The uranium extracted from the diffusion barriers will be reused.

Likewise, the processings by thermal processes leading notably to the mineralisation of organic compounds are to be considered, such as that described, for example, in the previous section related to research on the conditioning of HL/IL-LL waste.



3.6.2. Optimising the distribution of waste between management routes

A working group led by DGEC, including ASN, DSND, Andra and the main waste producers (Areva, CEA, EDF, Rhodia), will be responsible for defining optimisation lines for the distribution of the waste between management routes.

The entire management route from the production of the waste to its disposal will have to be considered.

Insofar as a global optimisation of the management of all the French radioactive waste is difficult to accomplish, studies per waste type, processing type or disposal solution may be considered.

More precisely, the working group will be responsible for proposing progressive industrial scenarios which optimise the distribution of the waste between the VLL, LL/IL-SL , LL-LL and IL-LL management routes. This optimisation is understood to be the definition of, if possible upstream from where the waste is produced, the best processing and disposal management route in proportion to the risks linked to each waste (notably in terms of dose with an ALARA optimisation), with the ″'disposal volume' resource being considered a ″rarety″, and taking into account the technico-economic aspects″. **The working group will submit at the end of 2011 a proposal of optimised distribution modalities of the waste flows between the existing management routes or those in the project stage, and the estimated inventories per derived management route. A methodology will be proposed at the end of 2010.** The group will study in priority the case of the waste containing long lived elements in order to consolidate the estimated inventory model of the LL-LL waste disposal project and will pay particular attention to waste conditionings.

3.6.3. Studies in human and social sciences

Academic research on the nuclear

As expressly demanded in the 2007 PNGMDR edition and by the Scientific Council of the CNRS, the PACEN programme is devoted to the development of its research component in the field of the social sciences (ACSSON). A priori, this component should cover all the society's issues concerning the civil nuclear sector. The tackled topics go far beyond the traditional issue of the radionuclear risk and how it is perceived by the public. A spectrum of topics were thus evoked among which foreign experiences both for the civil nuclear as a component of the nuclear power production system as for the social problematic of the management of the waste generated by this production. The players communication methodologies (pro or con), the meaning of a nuclear said to be ″sustainable″, the evaluation of the benefits from transparency, and the specific aspects of French and international law are topics which also deserve consideration. Finally, it would be important to review all the studies of an economic nature in the widest sense, that is, including the environmental impacts. Therefore, there is a wide variety of topics for which a reflection by the social science community would be extremely enriching for the PNGMDR's research programme.

To take into account the operating modalities of the HSS community, it seemed more effective for PACEN to avoid trying to hierarchise the topics on which an action would be launched. Rather, a broad and undifferentiated exploration was instituted to identify one or several researchers who would agree to bring a relevant project. They were left the possibility to alter the topic and organise a seminar or another form of activity. Therefore, PACEN is committed to leaving the players the greatest degree of freedom to define the format of their action. Once a certain ″critical mass″ is reached, an attempt will be made, if possible, to structure the actions which it will have been possible to launch as a consistent whole. Initially, therefore, ACSSON will be more an envelope of juxtaposed actions than a unified programme.

At the end of 2007, ACSSON organised a seminar on the topic of temporality versus the nuclear. The conclusions of this seminar will be reported in 2009. The topic entailed analysing the way in which the long nuclear time scales ranging from a decade to hundreds of thousands of years can be assimilated by a society whose evolution rates range rather from a few months to a political office term. The year 2009 inaugurated an ALIEN seminar on Germany. During the first year, ALIEN will study how the ideas on the civil nuclear have evolved in Germany since the end of World War II up to today's situation and the implementation of the ″get out of the nuclear″ doctrine. The year 2010 will be devoted to analysing the energy and climate dilemmas associated with the present situation and the ways of possibly resolving them. An action on legal rights and the nuclear is currently in preparation.

Research in the human and social sciences at Andra

By defining its research policy in the human and social sciences (HSS), Andra aims notably at interesting HSS researchers in the work of Andra and progressively mobilising this community around topics of common interest. The thematic of reversibility was chosen for this reason and as a first step in order to incorporate social aspects in the design of the future disposal centre and to favour exchanges with the recipients (cf. section 3.5.4).

Research topics specifically oriented toward HSS are regularly proposed in the Andra doctoral theses allocation programme such as the economic approach of reversibility, a topic which is already under study for a doctoral research programme.

From a long-term perspective, the role of mediation between the technique, politics and the social that Andra is dedicated to playing in order to develop an expertise with a political finality should be examined in a reflexive way. The strategic orientation of the organisation will therefore be a topic for a very important investigative endeavor in the near future for which the HSS community's contribution seems vital.

In addition to the aforementioned research strategy and with a more operational objective, occasional studies were also proposed within the catalogue of scientific programmes for the HL/IL-LL and LL-LL waste projects. These studies dealt with issues ranging from the perception of risks to their society-based consequences, from the development of territories to the concertation modalities, or from temporality to management over long time scales. Less directly oriented toward research, they aim mainly at collecting information and elaborating advice for the Agency with respect to the present day situation of the various projects.

Conclusion

The management of radioactive materials and waste does not present today any significant risk with respect to the protection of people and the environment, even though evidently zero risk does not exist. In France, this management is controlled entirely independently from the viewpoint of safety and radiological protection by the Nuclear Safety Authority (ASN) and the Delegate for the Nuclear Safety and Radiological Protection of facilities and activities interesting Defence (DSND).

Today 85 % of the radioactive waste volume has long-term management routes ; the remaining 15 % is being temporarily stored pending such long-term solutions. Even though the management framework set up is therefore now solid, progress still must be made, in particular, to define the long-term management routes for all the waste.

The first edition of the PNGMDR published in 2007 had identified several types of radioactive materials and waste (low level and long lived waste ; high or intermediate level and long lived waste ; tritium-bearing waste ; disused sealed radioactive sources ; mining residues ; waste with enhanced natural radioactivity ; radioactive materials for which no reutilisation process has still been implemented ; etc.) which necessitate the implementation of new management routes or the improvement of existing management routes. With this in view, this edition prescribed the studies and the research to be conducted for each of these types of waste. This new edition of the PNGMDR relies to a great extent on the results obtained from these studies and research. The national inventory of radioactive materials and waste published by Andra in mid-2009 was also especially useful, notably for the evaluation of the perspectives of waste production in the upcoming decades, as well as for the evaluation of storage needs.

The PNGMDR edition 2010-2012 proposes to pursue and intensify the actions engaged since the publication of the previous edition on several topics, notably :

- studies and research must be pursued for the future entry in operation of two long-term disposal centres which will accommodate low level and long lived (LL-LL) waste and high or intermediate level and long lived (HL/IL-LL) waste ;

- management of reusable radioactive materials whose effective reusability is presented and analysed in this PNGMDR must be studied as a conservatory measure in case they would be eventually qualified as waste ; thorium-specific studies will be considering the reservations made about the reusability of thorium ;

- concerted research and development efforts must be assigned to the conditioning of high or intermediate level and long lived (HL/IL-LL) waste. Studies are to be pursued to reduce the volume of waste, to obtain a more inert physico-chemical state and, more generally, to improve management safety. The research efforts must be especially stressed on the conditioning of the IL-LL waste produced before 2015 for which the Act specifies that it should be conditioned at the latest in 2030 ;

- recycling in the nuclear sector of waste originating from the dismantling of nuclear facilities must be encouraged. AREVA, CEA, EDF and Andra must combine and increase their efforts to implement these management routes ;

- storage facilities proposed by CEA for tritium-bearing waste offer a concrete solution for ensuring the short- and medium-term safety of the management of this waste pending its accommodation in existing elimination management routes or routes to be created ; the proposed approach must now be implemented. Operational solutions for the tritium-bearing waste without a management route originating from the ″diffused nuclear″ sector, for which current management methods are often inappropriate, must however still be studied ;

- reinforcement of the quality of the coverings of the mining residues disposal sites, which in light of the results of the long-term impact evaluations, seems to be on several sites an effective solution. This reinforcement must be studied further in order to evaluate its feasibility and the relevance on all the mining residues disposal sites. Provisions dealing with the improvement of the knowledge about the sanitary and environmental impact of old uranium mines and the management of waste rocks must also be implemented ;

- an inventory of the management routes for the reuse of residues containing enhanced natural radioactivity must be drawn up and storage routes for industrialists producing occasionally waste with enhanced natural radioactivity must be found ;

- several work orientations for the management of disused sealed radioactive sources are to be implemented, notably to allow identifying the disposal management route and optimising the planning for the recoveries and collections of this waste.

The new PNGMDR edition 2010-2012 is also the occasion to treat new topics not discussed in the previous edition, notably :

- the storages of old waste, for which an inventory of the engaged actions or the actions to be engaged to destore them is drawn up. The basic nuclear facility operators should also determine a programme to verify that there does not exist in the perimeter of their facilities or their centres historical waste disposals which would have been omitted in the declarations submitted to Andra for the national inventory established in 2009 ;

- the waste stored on the Comurhex site at Malvési in lagooning basins for which AREVA should propose safe long-term management routes ;

- the mining waste rocks for which it seemed important to consolidate the reuse sites and to check the compatibility of the uses directly above them and in the immediate environment of the zones where these waste rocks were used in the past ;

- the improvement of the global consistency of the management of the radioactive materials and waste by watching over the exhaustiveness of the management routes and optimising the distribution of the waste between the management routes.

This new version 2010-2012 will be communicated to Parliament at the end of 2009 and will undergo an evaluation by OPECST. A new decree fixing the prescriptions of the PNGMDR will be published in 2010 to formalise the main demands or studies to be conducted.

The work is far from finished, and there are still many challenges to meet before each radioactive waste has a long-term management route. With the publication of this new edition of the PNGMDR, however, a giant step has just been made in the improvement process for the management of radioactive materials and waste.

Annex : Summary of the achievements and research conducted in foreign countries

I. Summary of the achievements abroad

This summary presents the achievements abroad concerning the management of radioactive materials and waste (countries accounted for : Germany, Belgium, Canada, China, Spain, United States, Finland, Japan, Netherlands, United Kingdom, Sweden and Switzerland). The notion of ″achievement″ is interpreted in a rather broad sense including, in particular, the elaboration of the legal framework and the definition of a radioactive waste classification.

I.1. Elaboration of a legal framework

Radioactive waste management plans (more or less close to PNGMDR) sometimes exist abroad, but with objectives varying very much from one country to another. In addition, some of these plans are not rendered public.
In Spain, the General Plan for Radioactive Waste, which is regularly revised, simply corresponds to general directives on the institutional level.
In Belgium, the Ondraf must also draw up a Waste Plan around 2010 to establish the various long-term management routes and analyse their environmental incidences.
In the United Kingdom, the White Book titled Managing Radioactive *Waste Safely - Proposals for developing a policy for managing solid radioactive waste in the UK* announces a plan and an organisation for managing waste.

In terms of inventory, the practices vary, notably with respect to its perimeter (the French specificity on VLL waste, the inclusion of mining waste in the United States), its exhaustiveness and its level of detail (less detailed in Germany than in France), its dissemination to the public (non-public inventory in Spain ; in Japan, producers are free to make their own inventories public or not), its updating rate, and its processing of so-called ″engaged″ waste based on the current production rate (up to 2080 for Germany, but, on the contrary, no accounting for the moment of engaged waste in Belgium or the United States).
Despite the work of the IAEA (which makes available to all the countries a common database, but with a relatively global approach and very large categories), comparisons remain difficult, notably because the reference units (volumes, weights, etc.) for measuring the quantities of radioactive waste vary from one country to another.

Like Andra in France, a public agency is responsible for implementing the management of radioactive materials and waste in Belgium (ONDRAF-NIRAS) and in Spain (ENRESA). A public agency exists in the Netherlands, COVRA, but it is not really comparable either in terms of the perimeter of covered waste or in terms of activities. However, the waste producers (notably private entities) are mostly those who are directly responsible for the practical implementation of waste management. Then they create a cooperative to manage certain waste in cooperation with the public producers : Canada (NWMO-SGDN), Finland (Posiva Oy, only for spent fuels), Sweden (SKB), Switzerland (CEDRA-NAGRA, which does not manage the storage). Sometimes there is no centralised agency, notably in Japan, where a management route and an agency correspond roughly to each type of waste. It should be noted that these agencies are not systematically the ″owners″ of the waste which they have to manage : in Canada, the producer remains responsible even after the closing of the disposal centre ; in the United States, the state is responsible for the civil waste starting from the transport phase (followed by the disposal after landfilling and the disposal after site shutdown phases).
The list of agencies in charge of radioactive waste is given in the table below :

Country	Agency		Status	Creation date	Comments
Germany	BFS	Bundesamt für Strahlenschutz	governmental (BMU)	1989	
Belgium	ONDRAF	Organisme national des déchets radioactifs et des matières fissiles enrichies	public	1980	
Canada	NWMO	Nuclear Waste Management Organization	private	2002	Geological disposal of CUs
China	EEE	Everclean Environmental Engineering Corp.	public	1995	
Spain	ENRESA	Empresa Nacional de Residuos Radiactivos, S.A.	public	1984	
United States	OCRWM	Office of Civilian Radioactive Waste Management	governmental (US.DOE)	1982	
Finland	POSIVA	Posiva Oy	private	1995	Geological disposal of CUs
France	ANDRA	Agence nationale pour la gestion des déchets radioactifs	public	1991	
Japan	NUMO	Nuclear Waste Management Organization of Japan	public	2000	Final disposal of HL waste
Netherlands	COVRA	Centrale Organisatie Voor Radio-actief Afval	public (since 2002)	1982	
United Kingdom	NDA	Nuclear Decommissioning Authority	public	2005	
Sweden	SKB	Svensk Kärnbränslehantering AB	private	Years ‘70	
Switzerland	NAGRA	Nationale Genossenschaft für die Lagerung radioaktiver Abfälle	private/public	1972	

For the funding of radioactive waste management, the pollutant/payer principle seems to be universally applied for the management of radioactive waste facilities, but not for research on waste management.
It should be noted that all the countries mentioned here (except China which is in the adhesion stage) are members of the IAEA’s Common Agreement on spent fuel management safety and on radioactive waste management safety which entered in force on 18 June 2001.

I.2. Radioactive waste classification

Two main approaches exist to define the classification of radioactive waste : one approach per waste management route and one approach per waste production management route (this latter approach being in part inherited from the historical construction of radiological protection, generally built per production management route).

Within the first approach (per management route), the classification abroad often combines like in France the activity and lifetime parameters of the radioelements making up the waste (e.g., Belgium, Spain). It should be noted that the IAEA recommended a classification of this kind in the Common Agreement (on spent fuel management safety and on radioactive waste management safety).

However, the waste classification relies sometimes only on the activity. For example, in Canada, there are only two main categories (LL/IL, and HL + spent fuels), if the specific management of waste originating from mines is excluded. In the Netherlands, the classification includes a larger number of categories, but no distinction is made between short live waste and long lived waste ; as a result, there is no surface disposal project.

Other classifications (leading to qualitatively comparable categories, but with quantitatively distinct thresholds) sometime exist : Germany, for example, has based its classification essentially on the exothermic nature of the waste.

In the countries which have adopted the second approach (per production management route), the classification is more complex, with management routes specific to certain types of waste and combining activity and lifetime : the US, Japan and Sweden (where both approaches co-exist in reality for this last country). Finally, a category is sometimes added for waste originating from hospitals, universities, etc., particularly in Finland.

In addition, some categories correspond to national specificities : Belgium (processing 50% of the radium sources used in the world), Canada (important uranium mines).

Finally, the absence of a release threshold in France (for waste containing or liable to contain only very small quantities of radioactive elements) is a specificity. Such thresholds exist in the other studied countries, but vary significantly for the considered threshold itself as well as for the perimeter of the considered waste ; the VLL waste category exists, therefore, rarely as such and hence does not correspond to the same waste as in France.

II. Existing management routes or management routes under development

II.1. Choice of the type of fuel cycle

Several countries considered in the study decided to process spent fuels and construct facilities for this purpose : the United Kingdom (whose facilities recently faced shutdown periods, but whose operation would be authorised until 2012) and Japan (always in reality about to go into industrial operation). China also opted for a closed fuel cycle, but still does not have any operating facility (simple facilities construction project, notably assisted by France).

Most of the countries that have not constructed dedicated facilities on their own territory had removed or still remove all or part of their spent fuels in plants abroad, notably Germany, the Netherlands, Switzerland and very partially Spain. However, most of these countries have decided to terminate processing abroad in the more or less long term : Germany and Switzerland notably committed to do so by law. Belgium also suspended its waste processing contract with Areva in 2000. Some of these countries are reflecting, however, on an evolution in this doctrine.

The other option, which consists of directly managing spent fuels with neither a separation nor a processing phase, continues to be retained in Canada, Finland and Sweden. This is also the case in Spain and the United States (since the Carter presidency), but both of these countries do not exclude processing their spent fuels in the future.

II.2. LL/IL waste management

In most cases, projects for surface and sub-surface disposal centres at precise locations are being elaborated or even already in operation. It should be noted that the projects vary widely in terms of the type of site selected, the design of the disposal centre, as well as the depth ; these factors condition in the end the type of waste which can be disposed of (notably concerning the lifetime). Thus, in Belgium, the Dessel disposal centre which should go into operation in 2016 will accept only low or intermediate level and short lived (LL/IL-SL) waste. Among the other projects realised or to be realised, here are a few worth mentioning : the project in Canada near the Bruce reactor in Ontario ; the Beilong disposal in China ; the El Cabril disposal in Spain ; the centres of Barnwell, Richland, Clive and Andrews in the United States ; those of Olkiluoto and Loviisa in Finland dug in granite to a depth of 60-100 m ; that of Rokkasho-Mura in Japan ; that of Drigg in the United Kingdom ; and the SFR centre of Forsmark in Sweden located under the Baltic Sea. A geological repository is to be implemented in Germany beginning in 2014 for LL/IL waste in the old Konrad iron mine at Salzgitter.

Some countries still do not have an identified project for the disposal of low or intermediate level waste and, as a result, have opted for a simple storage pending a perennial solution, notably the Netherlands and Switzerland.

On the other hand, some LL/IL waste disposal sites are already full : Asse (initially dedicated to the study of the disposal of radioactive waste, but which became in fact simply a disposal) and Morsleben (exploited until 1998 and currently being closed) in Germany, and Dounreay (for which a new project is being examined) in Scotland, the United Kingdom.

More specifically, for LL-LL waste, current management abroad consists of essentially storing it on the production site. Therefore, long-term management routes remain to be defined. Volumes are especially large in Belgium : the radium waste originates from the processing of 50% of the radium sources used in the world and is currently stored on the Olen site. In Spain, the graphite waste originating from the graphite moderated, gas cooled, natural uranium reactors management route is currently stored on a reactor dismantling site. There does not exist a formal plan any longer in Switzerland and the United Kingdom, both of which possessing graphite waste.

II.3. HL waste management

All the countries are oriented toward the deep geological repository, but are at very different stages in the site selection and centre construction processes.

Finland and Sweden have already selected their (first) sites, respectively, at Olkiluoto and Osthammar (community of the Forsmark electronuclear site). These centres are to go into operation between 2020 and 2025. In Finland, an underground qualification laboratory, Onkalo, is being dug on the future disposal site. The targeted depth of 500 m should be reached in March 2010, and the digging of the infrastructures terminated in 2012. In Sweden, the site was selected in June 2009 after several years of detailed studies and investigations, and with an extensive experimentation programme for the laboratory of Aspö (close to the unretained site of Oskarshamn). The programme calls for an authorisation application to be filed by the end of 2010, an authorisation after 2013, the start-up of the work in 2015 and entry in operation in 2023.

In the United States, after the selection of the Yucca Mountain site in 2002, the US-DOE (OCRWM) filed a disposal construction authorisation application in June 2008. Since the application was judged to be conforming, its examination was accepted by the Nuclear Regulatory Commission (NRC) in September 2008. Early in 2009, the funds allocated by the new administration forecast delays and even a reconsideration of the project. The budgets for 2009 and the demands for 2010 confirm this tendency. The group of experts, the ″blue ribbon panel″, should be shortly formed in order to propose substitution scenarios and a study of alternative solutions, taking into account the option of reprocessing spent fuels.

Even without the site having been selected yet, more or less long-term timetables have been fixed in some countries. Japan launched a process to select a disposal site for vitrified waste which should go into operation around 2035 ; however, the process has been blocked in its phase 1 since July 2007 due to a lack of candidatures ; a new information campaign was engaged in 2009 in preparation of the issuance of a new request for candidatures. Germany and China fixed objectives for the start of the exploitation of the geological repository, respectively, beyond 2030 and 2040. In Germany, work on the Gorleben site was suspended in 2000 on account of a 10-year moratorium. The project should, therefore, resume during 2010.

Other countries have decided to concentrate on research on the geological repository and push off the the selection of a particular site. For example, no timetable has been set in Belgium, Canada (where the process is progressive), or Switzerland. In the United Kingdom, the Commission on Radioactive Waste Management (CoRWM) proposed to leave open the possibility of storing the waste for a period of approximately 50 years before disposing of it. The NDA defined a new concertation framework to search for a site and several candidates around the Sellafield site in Cumbria have since reacted. An agreement was signed by the Cumbria Country Council and NDA and the exploration work on the site could resume as of 2010 under the British Geological Survey (BGS). Likewise, the Netherlands has constructed a storage for a long duration (on the order of a century) ; the geological repository should be studied before then. As for Spain, it decided in 1999 to not make any decision about the disposal site before 2010, and to not undertake any search for a disposal site before that date (but a request for candidatures was issued for a centralised storage).

III. The disposal as a reference solution

In most of the countries, the reference solution for the management of high or intermediate level and long lived waste is the deep geological repository. The host rocks are chosen according to their qualities and the geological possibilities of the concerned countries.
No country has still delivered a formal authorisation to dispose of this waste, including spent fuels, except the US for military waste[28]. The progress level of the projects varies according to the countries.

Scientific and technical feasibility can be considered in some cases as acquired and the most advanced countries are at the stage of the final qualification of the site and of the optimisation of the concepts and engineering.

Most of the countries like France have faced large slippages in the development of their disposal programme due to the attempts to search for a site on mainly scientific and technical bases without sufficient local concertation. Those who were able to learn from their mistakes and restart the process from its initial stage with prior debates and concertations are today the most advanced.

III.1. The research organisation

For research programmes concerning radioactive waste without an existing industrial management route, the most general case consists of conferring the control to the agency responsible for the management whether public or private : SKB in Sweden, POSIVA in Finland, ENRESA in Spain or ONDRAF in Belgium.

This configuration implicates, however, a special technical support similar to that of Andra which received research agencies such as CEA : POSIVA with VTT, NAGRA with PSI, ENRESA with CIEMAT, ONDRAF with CEN-SCK.

Nonetheless, for historical reasons, R&D can sometimes be driven by another agency, which associates the future waste management operator and other research agencies.

Germany is a typical case, with a strong implication of GRS (research agency dependent on the BfS waste manager) and BGR (the Basse Saxe office of geological studies) in the exothermic waste repository file. DBE intervenes for engineering.

Japan is another special case, although more simplified since the merger of two public research agencies, JNC and JAERI, into JAEA. JAEA is backed by CRIEPI, funded by nuclear electric power companies, and RWMC, funded by METI.

III.2. The underground research laboratory, whether a prior disposal project or not

The various configurations of the waste management organisation in the different countries under consideration are evidenced in the R&D for the geological repository (spent fuels (CU) or HL and IL-LL waste) by a wide variety of underground research laboratory statutes, whether in terms of property or objective (methodology[29] or qualification of the site and the host rock).

[28] The WIPP (Waste Isolation Pilot Plan) went into operation in March 1999 in the Southeast of New Mexico. It is a transuranian military waste disposal centre located at a depth of 635 m in a salt layer.

[29] That is, a laboratory whose objective is to fine tune the ″in situ″ characterisation techniques , but which due to its statute and its geological environment is not located in a possible geological installation sector.

In Sweden, the Hard Rock Laboratory of Äspö is the property of SKB (granite methodology and qualification). Since 1995, it has been conducting in-situ research on its concept KBS3 (with vertical cells) within the framework of three-year R&D programmes approved by the Government. Since 2000, design demonstrators are operational. The purpose of these programmes is to acquire the control of the construction and operation methods of a deep geological repository whose authorisation should be filed for in 2010 (excluding the Äspö site).

Recent research involved the study of a KBS3 alternate with horizontal cells. Endurance test are being performed on the emplacement and retraction system of a 50 tonne assembly (container and its bentonite hull) inside a tunnel 90 m long and 1.80 m diameter. Early in 2009, these tests represent already a cumulated total of movements inside the tunnel of more than 300 km.

In Finland, POSIVA is drilling into granite at Onkalo a qualification laboratory installed at the same site as that of the future disposal centre. In March 2009, the drilling operation had reached a depth of 330m with a ramp approximately 3500 m long. Three raise-bored shafts had reached a depth of 290 m for the deepest. Research is directed on geological surveys, instrumented borings, characterisation niches and mechanical studies on the crystalline massif.

In Belgium, the Hades research laboratory located at a depth of 230 m has a methodological goal and is used for the qualification of the Boom argile. It is now managed by an EIG membered by ONDRAF and CEN/SCK, the Belgian counterpart of the CEA. This laboratory demonstrates the possibility of constructing a geological repository consisting of a network of drifts with limited disturbances within the host argilaceous formation.

Current research using the PRACLAY design demonstrator focuses on the consequences of the exothermic waste disposal (HL waste and spent fuels) in the near field and in the host argilaceous formation. PRACLAY is designed based on a representative generic concept of the Belgian reference concept of a super container in a horizontal cell with a wedge block ground support. The test drift has a length of 45 m (and a diameter of 2.5 m). The ten-year thermal phase will commence in 2010.

Switzerland has two laboratories with very different statutes :

- GTS (GRIMSEL Test Site), a methodological laboratory in a granite medium made available to NAGRA starting from drifts belonging to the nuclear electric power companies ; current research concerns the instrumentation and the monitoring of the structures. However, the demonstrator of the Spanish spent fuel disposal concept in the drift, FEBEX, installed by ENRESA in 1997, is still active.
- Mont Terri, an international consortium initiated in 1996 by NAGRA and Andra and now directed by a Swiss federal authority. The laboratory presents methodological objectives. It is allowing Nagra to qualify the clay at Opalinus (potential host rock), and Andra to prepare its teams for the characterisation of the Callovo-Oxfordian clay.

At Mont Terri, a hundred experiments of unequal importance have been performed since the beginning of the research programme and thirty are still in progress in 2009. In an argilaceous material which had not been studied very much previously, the rock's characterisation methods were set up. Thus, in relation with safety, the radionuclides' diffusion in the clay was measured ; the water contained in the rock was collected. A laboratory extension was dug in 2008.
The extensive participation of Andra in the projects and experiments at Mont Terri allowed Andra to prepare experiments in the Meuse/Haute-Marne underground research laboratory.

In Japan, JAEA is constructing two underground research laboratories (in geological media of sedimentary and crystalline rock) with strictly methodological objectives. At the Horonobe site on the Northern island of Hokkaido two shafts are being drilled. These shafts will reach in March 2009 depths of 250 m and 140 m of the planned 500 m. At the Mizunami site in the central island of Honchu two shafts are being drilled in the crystalline rock medium. They will reach in March 2009 depths of 300 m of the planned 1000 m.

In Germany, after the experiments conducted during the 1990s in the old Asse salt mine, the Gorleben site (virgin salt dome) was in turn characterised. Even though authorisations had not been granted, the nuclear electric power companies considered that they had acquired its qualification in the future

disposal site. The objective consisted then of specifying the concepts and the engineering. For instance, the Gorleben site was excavated taking into account the dimensioning for a disposal.
This ″look ahead″ approach is at the origin of many socio-political problems explaining in part the delay of Konrad and the uncertainty on the future autorisation of Gorleben.

In the United States, an authorisation application was filed in June 2008 for the disposal of spent fuels in volcanic rock at the Yucca Mountain. It is being evaluated. New experiments were suspended in January 2008 due to budegetary pressures exerted on the project. In February 2009, new budgetary pressures affected all the studies in relation with Yucca Mountain. The project along with the research on it is being politically reconsidered by the Federal Government which intends to re-define the strategy for disposing of radioactive waste and spent fuels.

III.3. Coordinated research in Europe

This research is taking place within the framework of the PCRDs funded by the European Commission. On 12 November 2009, a technological platform was installed with the objective of targeting better the research, development and demonstration (RD&D) programmes and ensuring a better coordination of research between the Member States. To this end, the IGD-TP platform (Implementing Geological Disposal Technology Platform) driven by the agencies in charge of the geological disposal projects in the European countries also unites research agencies, design & engineering firms, technical support organisations (TSOs) of safety authorities, as well as all the players interested or implicated in the research programmes. A vision document was released on the occasion of the launching of the platform with as a framework ″the start-up of the first geological disposals by 2025″. The years 2010 and 2011 will be especially devoted to the elaboration of a strategic research agenda (SRA) listing and hierarchising the RD&D needs and a development plan for its implementation. The projects funded by the European Commission should be founded on the priorities expressed by the platform.

III.3.a. Gas transfer
The elaboration of the European project FORGE has united the efforts of the main players at the European scale on the problematic of the effect of the gases produced in radioactive waste disposals.
Thanks to it, a preliminary summary of the state of knowledge could be made and mutualised actions could be defined. This project includes an experimental part implicating the four underground research laboratories of Äspö (SKB) with the current experiment LASGIT, Mont-Terri, Mol (Ondraf) and Bure (Andra). Modelling and experimenting are accomplished together. FORGE was launched at the end of 2008 for a 4-year period.

III.3.b. Packages
Participation in the European project MICADO allows following the work of counterparts on spent fuels. Research agency and safety authorities representatives from several countries exchange models of internationally proposed source terms to describe the long-term behaviour of spent fuels. A common database of experimental data was created. Conclusions are awaited on the inter-comparative exercises performed on the models already developed from this database. Moreover, a point is made on the uncertainties associated with the input parameters of the models.

III.3.c. Radionuclide transfer
The European project 'Funmig' terminated at the end of 2008. It allowed establishing an enhanced knowledge base on the understanding of the processes and phenomena governing the migration of anionic and cationic radionuclides in argilaceous formations (Callovo-Oxfordian, clays at Opalinus, Boom clay). It led to the development of a unique model for monovalent ion diffusion and transfer, such as Cs^{137} and Cl^{36}, in argilite or bentonite.

III.3.d. Monitoring
Monitoring the geological disposal is a topic bringing together interested international partners. A work of collaboration, "EC Thematic Network on Monitoring", was conducted within the framework of the 5th PCRD. It led to the conclusion that even though each country is responsible for adapting the approach and the ambitions of monitoring to the national context (regulations, expectations of the recipients, the disposal management strategy), monitoring is a topic to be developed.

In 2008, Andra directed the establishment of a new programme of studies, MoDeRn, aimed at sharing among the various teams some reflective thinking and the development in terms of monitoring. Moreover, non-European partners, such as RWMC (Japan), DOE (US) and NWMO and AECL (Canada), expressed their interest in being associated with this project, which is programmed for the four-year period 2009 - 2012.

III.3.e. Physical and geochemical processes in the near field
The integrated European project "NF-PRO" (Understanding physical and numerical modelling of key processes in the near field, and their coupling for different host rocks and repository strategies) studies with higher precision the physical and geochemical processes affecting the near field of an underground high- or intermediate-level and long-lived waste disposal in order to understand their couplings and to introduce them in numerical simulations necessary for disposal performance and safety evaluations. The NF-PRO programme terminated at the end of 2008. The experimental studies and modellings yielded results and a new understanding of the processes affecting the overall performances of the near field. NF-PRO has a major strategic impact in Europe insofar as the project reinforced the necessary scientific and technical fundamentals for repositories.

III.3.f. Repository engineering
The integrated European project of engineering studies for the high level radioactive waste repository ESDRED (Engineering Studies and Demonstrations of Repository Designs) is conducted within the 6th master programme of the European Union (2004-2009). It is coordinated by Andra and brings together thirteen partners from nine European countries.
The objective of the project is to demonstrate with industrially-scaled prototypes the technical feasibility of the various construction, operation and closing operations of a deep geological repository. Within this context, several demonstrators were developed and tested, among which drift backfilling with bentonite, heavy load transfer on air or water cushion, vitrified waste package handling using a pushing robot, which also allows retracting packages in order to satisfy reversibility requirements. The demonstrators are exhibited by each of the participants. Andra in turn presents them in the dedicated building on the Saudron site, the CTe (Experimental Technical Centre).

III.3.g. Safety evaluation methodology
The integrated European project PAMINA (Performance Assessment Methodologies in Application to Guide the Development of the Safety Case) brings together 25 partners from 10 European countries for three years until September 2009. It consists of providing a very complete vision of the methods, tools and practices in terms of safety evaluation. It seeks to establish a framework and a methodology to treat the uncertainties which appear during performance evaluations and in safety arguments. It develops methods in concrete fields which intervene in the study of granite, argilaceous and saline media. It provides for the presentation of a state of the art of the safety evaluation methods and the supply of technico-scientific results drawn from national radioactive waste management programmes.

III.3.h. Graphite waste management
Directed by FZH (Forschungzentrum Juelich GmbH) in Germany, the European project Carbowaste was defined within the 7th research and development master programme of the European Union. Launched in 2008 for a four-year period, it brings together 28 agencies.
The objective of this project is to manage better graphite wastes originating from the dismantling of the first 1st generation nuclear power plant reactors called the "graphite moderated, gas cooled, natural uranium" (UNGG) or ″force tube″ (RBMK) reactors. It aims at specifying the characteristics of graphites irradiated with their contaminants and their properties in order to determine the impact on the various phases : removal, processing, conditioning, transport, storage and disposal.

III.3.i. Biosphere evolution
The European project BIOCLIM (Modeling sequential biosphere systems under climate change for radioactive waste disposal) coordinated by Andra brings together 12 partners from 6 European countries. This project, which focuses on the evolution of the biosphere over time for an application in five regions of Europe (including the Southeast of the Paris basin, the Meuse/Haute-Marne region, for France), took place from 2001 to 2003 within the framework of the 5th PCRD.
Its objective was to evaluate the importance of, for the transfer of radionuclides, the transitions between the various successive states of the biosphere and the interest of considering the order of

occurrence of these successive biospheres in the safety studies of long lived waste disposals. Since the biosphere sequences are by nature guided by the evolution of the climate, the project included a part dedicated to the simulation of the future evolution of the climate. These simulations allowed creating the first scenarios of a possible change in the climate over the next million years according to the various hypotheses on greenhouse gas emissions of human origin.
The results are presented in thirteen reports which give a complete vision of the accomplished work and the obtained results.

III.3.j. Regional repository
Even though this position is not officially declared, some European Union countries are waiting for the topic to be treated at the community level with the possibility of a regional geological repository, that is, a repository common to several countries. In this framework, it should be noted that the Euratom PCRD of the European Union funded the projects SAPIERR 1 and 2 concerning the feasibility of such a shared geological repository. The justification of such a facility relies as much on cost criteria, notably for countries with an installed nuclear base consisting of a few units, as on safety, but raises the problem of the installation country in terms of socio-politics.

III.4. OECD - NEA

The role of the Nuclear Energy Agency (NEA) is not to conduct research programmes, but rather to unite the players of the various countries to treat topics necessitating a shared engagement between the countries.

III.4.a. Reversibility
The topic of disposal reversibility surfaced in the framework of the geological repository and seems to have become a debate issue for acceptance by local communities and the public.
Based on this, this recent request appears only in countries which either have advanced programmes with local communities concerned by a future site (Sweden, Finland, US) or have resumed the process of searching for a site right from the beginning in public debates (Canada, United Kingdom).
In Germany and Belgium, the topic is not a current matter for the disposal and the implicated agencies do not mention it. It should be noted that in both of these cases the studied host rocks (plastic clay of Mol or salt dome of Gorleben) are not favourable for the technical implementation of reversibility.
The pressure from local communities wins out, as demonstrated by the LL/IL-SL waste surface disposal project of Dessel, Belgium, where the reversibility requirement was imposed by these same local communities hosting the Belgium operator ONDRAF.
At the international level, the NEA/OECD supports a French proposal calling for the definition of a reversibility scale developed for the geological repository. This scale is a communication tool so that the recipients can dialogue on a clear and shared basis.
NEA formed a working group on reversibility ; it has a membership from many countries, including Germany, Belgium, Canada, Spain, United States, Japan. IAEA also decided to participate in this work. An international conference is scheduled for 2010 in France on this topic.

III.4.b. The NEA project 'Sorption III' on the sorption of radionuclides
The SORPTION III project will publish in 2010 a document presenting a divided view on the good practices to be applied for the utilisation of thermodynamic models intended to justify the way in which the sorption of radionuclides is taken into account in the models and therefore in the safety files. This methodological framework is being developed by a group of international experts whose experience is based on various applications ranging from polluted soils to disposal studies.

III.4.c. Radionuclide behavioural database
The TDB project (improvement of the thermodynamic databases) is funded to date by 14 agencies in charge of radioactive waste management or research agencies in this field of activity. This project will be developed until 2011. Today, the work consists of finalising the reviews for certain elements, Fe (Part 1), Th, Sn, and to initiate the studies for others, namely, Fe (Part 2), Mo. The work entails updating the auxiliary data associated with natural media and the elements previously treated in the project, firstly the actinides. A workshop in 2009 will provide an assessment of the project and user needs.

IV. Research on separation-transmutation

The separation and transmutation of the minor actinides constitutes a widely developed research sector which focuses on many concepts and processes in various countries, essentially in order to reduce the long-term radiotoxicity of nuclear waste and often in relation with the study of 4th generation nuclear systems (notably in Japan and the United States). The analysis of these various developments reveals similarities in the approaches and the envisioned concepts and, of course, different options to implement them.

IV.1. Separation of minor actinides

Developments in the continuity of the "existent" (that is, downstream from the processes recovering uranium and plutonium, which in turn undergo R&D) are distinguished from research aimed at a grouped recovery of all the transuranians (downstream from an initial recovery phase of the greatest part of the uranium).

For the first, the studies conducted in EUROPE (EUROPART, ACSEPT projects) to JAPAN (NEXT concept) and more recently in the US (UREX+ concepts) call on extracting systems evidently different (fruits of a national upstream research which grew abundantly these last decades), but whose functionalities are equivalent and which can be closely connected to the processes developed in France for the "extensive separation" (diamides, alkyl phosphoric acids, selective complexing agents of the actinides, etc.). The envisioned process most often consists of two stages, the first to co-extract the actinides and the lanthanides, the second to separate the two groups.
The grouped separation was studied in the United States and, in particular, by ANL (Argonne National Laboratory) : it is the UREX concept related to the French concept GANEX in which, first, uranium is to be extracted without plutonium, which is then managed with the other actinides in separation operations of the downstream fission products.

All this research is still at the test stage, where tests are being conducted in the laboratory on a few hundred grammes to a kilogramme of fuel ; upstream research to develop new molecular architectures remains highly supported. The technological developments associated with the implementation of such processes remain very limited and studies with a prospective character on original extraction devices in a supercritical environment or exchangers on a solid support are to be noted.

Concepts not resorting to hydrometallurgy are not leading to significant developments except for the so-called "pyrochemical" processes (where elements are dissolved in salts melted at high temperature), generally associated with a metal fuel or (notably in the case of ADSs) a fuel with very special characteristics. Research in this field is very active, but experiments remain at the laboratory level and have not for the moment resulted in experiments of a breadth equivalent to those conducted on hydrometallurgical concepts (including in countries like Russia, which successfully realised in the past large-scale developments for the pyrometallurgical processing of oxide fuels).

Conversion into fuels or targets of recovered actinides is also a subject of research and development of processes : here again research is limited to the laboratory, to the production for experimental irradiation needs of a few pellets or needles, generally implementing only americium (without curium) ; in addition to precipitation-calcination, more innovative concepts (direct denitration, sol-gel processes, etc.) are also being studied, but at a very preliminary stage.

IV.2. Transmutation of minor actinides

IV.2.a. Transmutation in critical reactors

Studies on transmutation conducted internationally on 4th generation systems concern essentially fast neutron reactors cooled with sodium. They consist of two parts : studies on the performances of transmutation of minor actinides in the reactor, and development and qualification of the associated transmutation fuels. They concern for the most part the homogeneous recycling mode, but the "charged coverings" concept is stirring up interest.

In Europe, the coordinated European project ESFR (for European Sodium Fast Reactor) is attempting to respond to the questions of feasibility concerning the development of a 4th generation RNR-Na. This is Europe's contribution to the GEN IV programme on the RNR-Na system.

This project provides for, in particular :

- the proposal of cores with optimised characteristics (reactivity effects, favourable natural behaviour, provisions to limit the consequences of serious accidents). These optimisation studies will be conducted on cores not only with an oxide fuel, but also with a carbide fuel. These studies (paper) have a very strong neutron component and integrate the issue of the impact of the recycling of the minor actinides on the core's characteristics.
- the fabrication and the determination of the physical properties of the fuels loaded with minor actinides (oxide, nitride and carbide). This second part is essentially experimental. More precisely, even though data on the fabricability of oxides containing minor actinides are available, nothing is known about the nitrides and the carbides. Moreover, it is provided for to fabricate representative samples of the heterogeneous recycling mode on the UO2 support and to proceed with measurements of the physical properties on these samples.

Other European programmes based on "analytical irradiations" aim at controlling the behaviour of the helium product under irradiation in fuels or targets with a high content of minor actinides (Marios irradiation in HFR).

Beyond, as part of the GEN IV programme on the RNR-Na 'system', the GACID project, which implicates the United States, France and Japan, concerns the recycling of minor actinides in the homogeneous mode and is intended to demonstrate at a significant scale this type of recycling (from several needles up to an entire assembly) in MONJU. Destructive examinations of the Am-1 irradiation conducted in JOYO are in progress and are providing precious data for the behavioural modelling of the fuel at the beginning of its life.

The United States is developing (AFCI programme) an irradiation programme centred rather on the homogeneous recycling mode in the ATR reactor of metal fuels (AFC-2A and B) and oxide fuels (AFC-2C and D) with the objective of rapidly reaching a high rate of burn-up with small samples.
Metal matrices are also a subject of interest ; a collaboration between CRIEPI and ITU with the support of CEA allowed realising in Phénix the METAPHIX irradiation representative of the recycling in the homogeneous mode of minor actinides in metal fuel.

Incidentally, the Advanced Fuels project in Gen IV is aimed at the selection of the 'best' advanced fuel (fissile compound, cladding and hexagonal tube materials) capable of very high burn-up rates and neutron doses. For the fuel, the candidates are oxide, nitride, metal and carbide.

IV.2.b. Transmutation in dedicated systems (ADS)

Several countries are actively working today on the ADS (Accelerator Driven System). On the one hand, Europe through several projects in the main programmes of the European Commission and, on the other hand, mainly Japan.

In Europe, the project of the 6th EUROTRANS PCRD is concentrating the most important part of the studies on the ADS system and its fuel loaded with minor actinides. This large-scale project, which was extended one year until March 2010, brings together 33 agencies from 14 countries plus a group of 18 universities. In 2010, several of the project's important results will be available : the first consistent designs of an ADS with performances, safety and an economic evaluation, the operational management of the coupling of an accelerator with a sub-critical mass, two fuels suitable for transmutation, the principles of lead's technology in the reactor.

Several other European projects are contributing to the studies on the ADSs :

- PATEROS, on the performances of an installed reactor base, including ADSs for waste management. The project is terminated and studies show that the RNRs and the ADSs have equivalent performances.
- VELLA, on the technology of liquid lead-bismuth. The project, which terminated the end of 2009, will have allowed coordinating the activities of European laboratories on the topic.

- MEGAPIE, on the fabrication and operation of a 1 MW spallation target with lead-bismuth. The target was successfully irradiated for four months in Switzerland the end of 2006. Post-irradiation examinations are in progress. The Paul Scherrer Institute proposes to develop a new target with a more industrial character.
- FAIRFUELS, the 7th PCRD, on fuels loaded with actinides on an inert support, has just gotten underway and completes the irradiations and examinations engaged in EUROTRANS.
- CDT, which has also just started, will conduct the preliminary project of the MYRRHA facility, a small ADS Pb-Bi based demonstrator provided for by the MOL centre in Belgium.

Finally, the GUINEVERE facility, a zero power model, still also at MOL, should provide the means to precisely drive a proton accelerator with a sub-critical mass.
Japan has its own ADS study programme. JAEA uses two small facilities with a proton accelerator and a spallation target. Beyond, it is planning within an international framework to connect the Linac of its J-PARC research centre to a mercury spallation target and a sub-critical mass of MOX fuel loaded with 5% minor actinides. As for the Kyoto University, it is conducting physics experiments with an accelerator and a solid target and is thinking about a major programme on a zero power sub-critical facility.

Annex : Detailed analysis of the adequacy between storage capacities and prospective radioactive waste volumes

The storage capacities available for conditioned waste packages are located on the production sites (essentially La Hague, Marcoule and Cadarache for HL and IL-LL waste). Each facility generally accommodates one or several waste families. Some capacities can be shared between the HL and IL-LL, IL-LL and LL-LL or even IL-LL and LL/IL-SL waste management routes.

Storage of the vitrified HL/IL-LL waste packages of La Hague

The standard vitrified waste packages (CSD-V packages and marginally the CSD-B packages to come) produced in the workshops R7 and T7 of the spent fuel reprocessing plants UP2-800 and UP3 of La Hague are successively placed in storage sites adjoining these facilities and then on the Extension of Glass Storages – South - East (E-EV-SE), when their thermal power falls below 2 000 watts.

R7 and T7 went into operation, respectively, in 1989 and 1992 for an estimated service lifetime of 50 years. E-EV-SE has been operational since 1996, and its final shutdown is not envisioned before 2040.

At the end of 2007, approximately 1 200 CSD-V packages[30] or 210 m^3 were stored in E-EV-SE pending shipment to the facilities of AREVA's foreign customers. Depending on the industrial and contractual conditions, the shipments should be completed for the most part in 2015 and entirely in 2025.

In 2015, the cumulated production of vitrified waste for France will reach a volume of 2 560 m^3. The annual production of vitrified waste packages on the order of 140 m^3 (800 packages) until 2027 will climb to 210 m^3 (1 180 packages) beginning in 2028 with the start of processing in dilution with the UOX and URE fuels of the 2 900 LMt of MOX fuels which will have been accumulated by this date.

The three storage facilities, R7, T7 and E-EV-SE, have a cumulated capacity of 2 174 m^3 which will be saturated in 2013. AREVA undertook in 2006 the study and the construction of an extension[31] of E-EV-SE, which will be operational in 2012 and will increase the capacity to 3 648 m^3.

Other similar capacities will be necessary starting from 2022 (see section 3.1.2). The production will last until the vitrification of the rinsing effluents which will be generated after the final shutdown of the plants UP2-800 and UP3 envisioned for 2040.

Storage of the vitrified HL/IL-LL waste packages of Marcoule

The Marcoule vitrification workshop (AVM) is equipped with a storage facility. The vitrified waste packages containing fission products and minor actinides from the past production (HL waste management route) and effluents from the rinsings of the circuits of the definitively shutdown UP1 plant (IL-LL management route) are stored here with packages containing the technological waste of the AVM (IL-LL management route) operation to which may be added the vitrified waste packages produced in very small quantities in the Atalante laboratories. The capacity[32] of the AVM storage site (665 m^3) is sufficient to accommodate all the productions provided for at Marcoule. The investigation of the safety re-examination of the storage facility of the Marcoule vitrification workshop led DSND to request demonstration complements from CEA in order to pronounce on the sustainability of this storage until the end of the recovery of the packages for their emplacement in the deep geological repository

A shipping interface for the shipment of the stored packages to the disposal centre should be developed by CEA taking into account the technical possibilities in terms of transport, the estimated needs in controls and reconditioning for disposal, and the possibilities of disposing of them over time. An identification of the technical options and a first analysis of the transport modalities will be made by CEA in concertation with Andra, notably for the presentation of storage-transport-disposal scenarios at the next public debate on the deep geological repository project.

The Marcoule pilot vitrification workshop PIVER produced a small quantity of vitrified waste packages (HL management route) for a total volume of 11 m^3 which are currently stored in building 213 specially engineered in the Marcoule pilot workshop (APM). It went into operation in 1969 and is expected today

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[30] Package volumes are estimated here from the unit volume considered in the national inventory, that is, 175 litres for the CSD-V package.

[31] Extension of the glass storage of La Hague : ″EEVLH″.

[32] The indicated capacity corresponds to the unit volume of 175 litres per container considered in the national inventory.

to operate for fifty years. An extension is imaginable ; it would allow preserving the PIVER packages here until their control and shipment to the disposal centre.

Storage of spent fuels for disposal without prior reprocessing

The uranium-based spent fuels used in certain graphite moderated, gas or heavy water cooled, natural uranium reactors, EL2 and EL3, the uranium-oxide-based fuels removed from the heavy water reactor EL4 of Brennilis in the Finistère department, or used for experiments or even subjected to appraisals after a stay in the fast neutron reactors, RAPSODIE, PHENIX, with pressurised water or research reactors CABRI, MELUSINE, PHEBUS, PFR, SCARABEE, SILOE, ORPHEE, and finally the ″caramel″ fuels of the OSIRIS reactor will not be processed and are to be disposed of after conditioning.

At Cadarache, these fuels are progressively placed under metal cladding in the STAR workshop and are stored in the CASCAD facility which went into operation in 1990 for an estimated service lifetime of 50 years.

The part reserved for these fuels in the CASCAD facility has a capacity of 4 770 packages. The total volume of the packages of spent fuels already conditioned represents approximately 51.5 m^3 (3 090 packages). In 2030, this conditioning will be completed and the total volume will be 74 m^3 (4 374 packages). Based on the data available today, the CASCAD facility's capacity seems sufficient to satisfy the storage needs of these unprocessed fuels until it is finally shutdown (CDE).

Storage of the compacted cladding waste of La Hague

Since 2002, the cladding waste (hulls and end-caps) of the fuel assemblings originating from the shearing workshops R1 and T1 of the UP2-800 and UP3 plants have been compacted with metal technological waste in the Compacting of Hulls workshop (ACC), which produces standard compacted waste packages CSD-C (IL-LL management route). The production of the CSD-C packages is scheduled to continue beyond 2040 in order to accompany the dismantling of the UP2-800 and UP3 plants.

On the La Hague site, the CSD-C packages are placed in the compacted hulls storage facility : ECC went into operation in 2002 simultaneously with the ACC for an estimated service lifetime of 50 years.

At the end of 2007, a volume[33] of 600 m^3 of CSD-C packages (approximately 3 270 packages) was produced in application of contracts with foreign customers. When terminated, the production should amount to 1 280 m^3 (approximately 7 000 CSD-C packages). Today, all the produced packages are stored in the ECC. Shipments to the facilities of foreign customers must commence in 2009 and continue beyond 2015.

In 2015, the cumulated production of the compacted technological and cladding waste packages for the French part will reach a volume of approximately 2 300 m^3 and in 2020 a volume of 3 135 m^3. ECC has a capacity of 3 806 m^3, which is sufficient at that date to accommodate the CSD-C packages CSD-C for the French and foreign parts. ECC has a modular design with a land reserve which would allow, if necessary, constructing up to 6 modules equivalent to the existing module. Saturation should occur around 2025.

Then the production of the compacted hull and end-cap packages will be increased with the beginning of the reprocessing of the accumulated MOX fuels in dilution with UOX and URE fuels.

The disposal of the CSD-C packages in the deep geological repository after it goes into operation would allow, in principle, optimising the capacity of an extension of the ECC facility (see section 3.1.2). The ECC facilty's extension should be studied with respect to the volumes of CSD-C packages produced by the reprocessing of the UOX, MOX and URE fuels, and with respect to the date when the packages will be disposed of.

[33] The indicated volumes and capacities correspond to the unit volume of 183 litres per CSD-C package considered in the national inventory.

Storage of both sludge and metal and organic alpha technological waste packages of La Hague

The STE3 effluent processing station has been processing since 1989 the liquid effluents of the La Hague plants. The sludge is embedded in bitumen and placed in stainless steel drums of 238 litres. These packages currently occupy a volume of approximately 2 600 m^3. They are stored in halls having a capacity of 4 760 m^3 in the S building of the STE3 station, which went into operation in 1987 for a scheduled operation until 2040.

Up to 2020, the STE3 station will be used for the conditioning of the first part of the rinsing effluents originating from the dismantling of the UP2-400 plant. A small number will be returned to AREVA's foreign customers within the framework of the contracts signed during the 1980s decade.

The STE3 station has also engaged in the bitumising of the sludge produced from 1966 to 1991 by the STE2 station of the UP2-400 plant, but production was interrupted and AREVA is studying an alternative conditioning.

Starting from 2013, AREVA envisions conditioning at La Hague alpha technological waste (contaminated essentially by plutonium) of the La Hague plants and the MELOX plant of Marcoule : metals, glass and organic materials. The conditioning hypothesis envisioned by AREVA is a compacting and a placement in a metal container. Production is provided for up to the dismantling of the plants beyond 2040.

In 2020, the already produced volume of approximately 2 600 m^3 will be increased by the sludge packages of STE2 produced by the alternative process and by the alpha technological waste packages. It will reach a total estimated at 6 090 m^3.

The additional required storage capacities will be provided by the destorage and storage-extension units of the D/E – EB bitumen drums in the ES building, which were constructed in 1995 for a scheduled operation until 2040. This facility located in the extension of the S building has a capacity of 6 426 m^3.

In 2030, the total capacity of the S and SE buildings, which is 11 186 m^3, will be sufficient, in principle, to store the productions of the previous packages, whose total volume will reach 9 533 m^3.

The sludge and alpha technological waste packages conditioned at La Hague will not generate, therefore, the need for a new storage capacity before 2040 if the alpha waste is compacted. Even though it is imaginable to dispose of the bituminised sludge packages around this date, the compacted alpha waste packages should still likely wait in storage for the decay of their production of hydrogen by radiolysis in a second generation facility which would thus be created (see section 3.1.2).

Storage of the solid operation waste, powdered waste, and cemented hull and end-cap waste packages of La Hague

Since 1990, the solid waste consisting of gloves, work clothes, toolings, and parts originating from operation and routine maintenance in the UP2-800, UP3 and MELOX plants or the dismantling of the UP2-400 plant are cemented on the AD2 workshop originally in cement asbestos containers (CAC) and since 1994 in fibre-reinforced concrete containers (CBFC'2).

These packages are emplaced in the solid waste facilities EDS/ADT2 and EDS/EDT - EDC (storage of technological waste and hulls) ; they are linked to the IL-LL and LL/IL-SL management routes. The flow of LL/IL-SL packages in transit in these facilities occupies a variable volume on the order of a few hundred cubic metres.

In the EDS/EDC facility, cemented stainless steel drums containing hull and end-cap (IL-LL) waste produced up to 1995 are also stored.

In the future, ECE stainless steel drums in which the powdered waste will be cemented will also be stored there : purification and filtration elements from the pool water and diffusion fines or fuel cladding removed from reactors of the graphite moderated, gas cooled, natural uranium type, which are awaiting conditioning on the facilities of the UP2-400 plant being dismantled.

The solid waste storage facilities have a total capacity of 14 331 m^3. They are supposed to remain in operation until 2040. This capacity seems sufficient until this date to accommodate the forecast production which will make the volume of IL-LL packages climb from 9 012 m^3 in 2009 to 11 125 m^3 in 2030.

Storage of the bituminised waste and solid waste packages on the Marcoule site

Since 1966, STEL, the liquid effluent processing station of Marcoule has produced sludge packages embedded in bitumen with a conditioning in steel drums of 230 litres. From 1966 to 1996, the drums were made of non-alloy steel and were stored in 35 pits located in the North zone of the site (approximately 6 000 drums) and then in casemates numbered from 1 to 13 located in the South zone (approximately 254 000 drums to which 2200 drums produced since 1996 and stored in casemate 14 are to be added).

An operation to recover and recondition these old drums was engaged. From 2000 to 2006, all the drums in the pits of the North zone classified to a great extent as LL-LL waste drums were removed, checked and placed in stainless steel over-packs of 380 litres (the over-pack container's internal volume). The recovery operation is being pursued with the old drums in the casemates 1 to 4 of the South zone. In parallel, to satisfy the requests of the DSND, the ″salting out″ drums will also be recovered (embedded IL-LL process waste drums stored mixed with bitumen embedded drums in the casemates 1 to 10 considered to be the source term).
Currently, the STEL station of Marcoule continues to produce bituminised sludge packages. Since 1996, the conditioning is made in stainless steel drums of 230 litres. These packages, which belong to the LL/IL-SL and IL-LL management routes, are stored in the casemate 14 which went into operation in 1994 with a capacity of approximately 1 200 m^3. The embedding workshop is scheduled to shutdown in 2014. On this date, the bituminised sludge drums linked to the IL-LL management route is expected to represent a volume of 518 m^3.
At dates ranging from 2017 to 2020, the following waste will commence to be recovered and conditioned :

- non-magnesian metal cladding waste originating from the fuels processed in the UP1 plant and cladding waste from the PHENIX fast neutron reactor ;
- powdered waste ; filters, powdered graphite from the uncladding of the UNGG fuels, settling sludge, and metal and partially organic solid waste originating from the operation and maintenance of the workshops or dismantling with beta – gamma spectra ;
- magnesian cladding waste from the UNGG fuels.

The sludge originating from the processing of the liquid effluents at the STEL station will be embedded in a cement matrix which will replace the bituminising of the sludge in 2014 (STEMA project). The waste packages (drums of 380 litres) containing to the great extent LL/IL-SL waste will be conditioned at the CDS before being shipped to the LL/ILDC-SL. IL-LL packages, if any, will be managed as packages originating from the processing of the powdered waste.
A multipurpose interim storage facility (EIP) went into operation in 2000 for the storage of the packages made up of 380-litre drums (called EIP drums). The EIP is a modular facility and currently consists of two cells[34]. Today, the facility is expected to operate for 50 years.
Today, the packages stored in the EIP facility are bituminised sludge drums produced by the STEL station before 1996, removed from the pits of the North zone and the casemate 1, and reconditioned in 380-litre drums. They represent a volume[35] of 2 660 m^3 (approximately 7 000 packages).
The pursuit of the recovery of the waste from the casemates and its placement in 380-litre drums will lead to a saturation of the current capacity of the EIP facility around 2016 with a volume of 4 370 m^3, that is, 11 500 packages (linked to the IL-LL and LL-LL management routes). A new capacity should then go into operation to allow pursuing the recovery programme.
If new EIP modules are constructed, the packages of bituminised sludge waste and cemented waste would represent in 2025 a total volume on the order of 9 000 m^3. After 2025, the volume of the waste stored at the EIP facility could be stabilised if the shipment flow to the disposal reached approximately 800 m^3 per year. The expected destorage would take place from 2038 to 2050.
The study of another strategy more favourable for the management of the disposal resource is presented in section 3.1.2.

Storage of highly irradiating IL-LL waste packages on the Marcoule site
The operations of recovering and conditioning old and dismantling waste will generate a highly irradiating IL-LL waste for which there does not exist a storage facility. For the Marcoule site, the volumes of this waste category produced by the dismantling of the PHENIX reactor (the most activated waste), as well as by the recovery of the cladding waste of the fuels processed in the pilot workshop of Marcoule (APM), are evaluated at approximately 253 m^3. To satisfy this need, CEA is supposed to create the DIADEM facility, which will go into operation in 2014 (see section 3.1.2). In addition, this

[34] Its extension may be envisioned up to 16 cells to increase the total capacity to 33 880 m^3.
[35] The capacities and volumes are expressed here in the unit volume of 380 litres considered for an EIP drum in the national inventory. Taking into account the overall outer volume of this package (441 litres) would lead to higher capacities and volumes for the same number of packages.

new facility will allow storing highly irradiating waste originating from the other CEA sites (Fontenay, Saclay, Grenoble).

Storage of slightly irradiating waste packages on the Cadarache site

Since 1970, the STE effluent processing station of INB 37 has conditioned the filtration sludge and the evaporation concentrates of the centre by cementing them in concrete containers of 500 litres. Episodically, this conditioning was made in 700-litre drums, which were reconditioned in a 870-litre container made of non-alloy steel. In 2012, the STE station will be replaced by the advanced management and effluent processing workshop AGATE.

The solid operation or dismantling waste originating from the Saclay, Fontenay-aux-Roses, Valduc and Grenoble sites is conditioned at the compacting - cementation station of INB 37. Sorting allows conditioning waste with a slightly irradiating alpha or beta – gamma spectrum by compacting and immobilisation in a metal container of 870 litres. Starting from 2017, the same conditioning will be used for the solid alpha-emitting dismantling waste originating from Marcoule.

All the previous packages are slightly irradiating (FI) and represent in 2009 a cumulated volume of 7 940 m^3 which will climb to 8 350 m^3 in 2030.

Until 2006, the IL-LL packages were placed for storage in INB 56, which no longer accommodates today new packages.

In 2006, CEA placed in operation at Cadarache the radioactive waste conditioning and storage facilities CEDRA : two new buildings no. 374 and 375 thus offer a capacity of 4 450 m^3 for the FI waste packages.

CEA programmed the removal of the FI IL-LL packages from INB 56 for sorting and storage in CEDRA.

At the end of 2008, the volume occupied in CEDRA was 533 m^3. The current FI storage capacity of 4 450 m^3 will not be sufficient to manage all the packages to be produced or removed from INB 56. In fact, the estimated cumulated FI waste volume around 2030 will be approximately 8 300 m^3. Also, CEA envisions increasing the FI storage capacity of CEDRA to 8 800 m^3 by constructing section 3.

It should be noted that the storage capacities to be reserved on CEDRA for old packages removed from INB 56 will depend on the complexity of the controls and reconditionings which it will be necessary to implement and spread out over time.

Storage of moderately irradiating IL-LL waste packages on the Cadarache site

The solid operation or dismantling waste originating from the various CEA sites identified by sorting as moderately irradiating (MI) waste has been conditioned since 1970 on INB 37 by immobilising it in a steel container of 500 litres. Until 2006 the waste was placed in the storage shafts of INB 56. Removal of the MI IL-LL packages from INB 56 has been programmed by CEA to be completed in 2018.

Since it went into operation in 2006, the CEDRA facility has the building no. 376 which is used to store in shafts the new MI waste packages or those removed from INB 56 for a capacity of 825 m^3.

Early in 2009, the cumulated volume of the MI waste stored on the Cadarache site was 1 052 m^3. It will reach 1 595 m^3 in 2030. The current capacity of 825 m^3 at CEDRA will not be sufficient to satisfy needs. CEA envisions increasing this capacity. After construction of the CEDRA section 3, it would reach 1 650 m^3 ; an additional section, section 4, would allow increasing the capacity to 2 350 m^3.

Storage of other waste packages on the Cadarache site

Waste packages containing radium-bearing lead sulphates[36], large size containers (1 000 or 1 800 litres) containing solid and filtration sludge waste, and ″source blocks″ are currently stored in INB 56. This storage represents finished productions having a volume of approximately 1 275 m^3. To remove from INB 56 these packages linked to the IL-LL management route, a new storage capacity corresponding to this volume will be necessary[37].

Storage of IL-LL waste packages on the CEA site of Valduc

The Valduc liquid effluent processing station produces coprecipitation / filtration sludge and concentrates. From 1984 to 1995, this waste was cemented in metal drums of 220 litres belonging to the IL-LL management route. The total volume of the IL-LL packages is 81 m^3. They are stored on the site.

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36 These packages originate from the processing of a uranothorianite ore between 1958 and 1970.

37 CEA envisions the construction of an ″interim building″ in section 2 of the CEDRA facility.

The processing of recyclable materials produces effluents containing americium, plutonium and uranium that CEA intends to vitrify after 2020. These IL-LL packages will also be stored on the site. In 2030, the total volume will reach 10 m^3.

Storage of EDF activated waste packages on the Bugey nuclear power plant site

Starting from 2014, the activated waste produced by the dismantling of the EDF reactors of Creys-Malville, Brennilis, Chooz A, Bugey, Saint-Laurent-des-eaux and Chinon, as well as the internal elements removed from the electronuclear reactors in operation : control and poison clusters will be conditioned in the ICEDA facility which is in the project stage on the Bugey site.

EDF has retained the hypothesis of a conditioning in reinforced concrete containers, the ″C1PG″ container, for the activated waste of the IL-LL or LL/IL-SL management routes (possibly after radioactive decay). In 2020, the expected IL-LL part will occupy a volume of 1 711 m^3, which will climb to 2 551 m^3 in 2030.

ICEDA will also process dismantling waste : metal waste from the LL/IL-SL management route and graphite waste from the LL-LL management route.

EDF envisions equipping the ICEDA facility with two storage halls each having a capacity of approximately 2 000 m^3. One will accomodate up to 1 000 IL-LL and LL/IL-SL waste packages in the C1PG container. The other is intended to accommodate in a first period 300 LL/IL-SL caissons of 5 m^3 and 10 m^3 and graphite waste packages.

Until 2020, the capacity of one hall is sufficient to accommodate the IL-LL packages in the C1PG container, provided the volume of the LL/IL-SL waste packages in transit to the LL/ILDC remains below 250 m^3.

In 2030, the capacity of the second storage hall will be in part used for the IL-LL packages in the C1PG container, which means that around this date it will be limited to the volume of LL/IL-SL and LL-LL waste packages awaiting shipment to their respective disposal.

Storage of miscellaneous and radium-bearing radioactive waste

Within the framework of the management of radioactive waste except for the electronuclear sector, Andra has storage capacities in the AREVA/SOCATRI and CEA facilities (INB 56 at Cadarache, INB 72 at Saclay) for diffused nuclear sector waste which belongs for the most part to the LL-LL management route. These storage capacities are limited in terms of waste type acceptance. Thus, Andra is unable to store either Ra-Be radioactive sources or liquid or gaseous sources, and hence cannot collect such sources. There are also limits on the deadlines to take care of irradiating objects, which sometimes exceed the needs. Finally, the CEA facilities are covered by dismantling projects. Also, Andra is studying new storage solutions for the management of waste from the nuclear sector and the collection and grouping of the waste from the hospital/university sector (see section 3.2.3).

Moreover, the radium-bearing waste linked to the LL-LL management route is stored by Rhodia, Cézus and CEA. A part is already in a conditioned form. Andra will analyse in concertation with the operators the adequacy of the storage capacities available for the prospective vision of waste and the possibilities of LL-LL disposal.

Annex : Research part of the PNGMDR

1. Introduction

The Act of 28 June 2006 fixed objectives and milestones. As such, it is a structuring element for the R&D work conducted on radioactive waste. So, the year 2008 was marked, on the one hand, by the publication of the decree fixing the prescriptions of the PNGMDR[38] and, on the other hand, by the recommendations of the CNE2 related to the research conducted in 2007[39].

The first document describes the management routes developed for the radioactive materials and waste and specifies a number of milestones which have paced the strategy of the research conducted for these past 3 years. The assessment of this research confirms these milestones for the upcoming years, except for the LL-LL project (see sections 3.3 and 4.2) for which the year 2008 was highlighted by the request for candidatures to accommodate an LL-LL waste disposal site. The second document (recommendations of the CNE2), in addition to the evaluations of the conducted research, proposes some orientations for the strategy to be implemented in order to comply with the fixed milestones.

The Act of 28 June 2006 conferred the responsibility of the separation-transmutation research to CEA and the research on the reversible disposal for HL/IL-LL waste to Andra. It assigns the tasks of the various players for the research in radioactive waste management. In parallel, a number of R&D actions are also performed by the industrialists (EDF and AREVA) in part in the framework of agreements associating them with CEA and/or Andra. All these agencies are supported as needed by the extensive competence base of CNRS, which has structured its research around a interdisciplinary research programme called PACEN (Programme on the Downstream of the Cycle and Nuclear Energy), Universities, and other agencies such as BRGM or INERIS. Finally, we should mention IRSN, whose research has a different final goal. It aims primarily at ensuring a satisfactory appraisal level so that it can play its technical support role to ASN and DSND. The IRSN research priorities for the period 2009-2012 are, however, presented in chapter 5 for information.

To ensure a consistency between all these programmes, a Committee for Research Orientation and Follow-Up Downstream from the Cycle (COSRAC) was set up : DGRI and DGEC alternately share the the presidency and DGRI is responsible for secretariat tasks. COSRAC, a unique upstream exchange platform between all the players in the research endeavour, helps implement a common strategy for the research related to the Act of 28 June 2006.

1.1. Milestones structuring the research conducted within the PNGMDR framework

The milestones concerning the LL-LL waste prescribed by the decree fixing the prescriptions related to the PNGMDR are as follows :

- **31 December 2009 at the latest :** Andra submits to the ministers of energy and the environment an analysis of the sites liable to accommodate a disposal of *"graphite and associated process waste originating from the dismantling of the graphite moderated, gas cooled, natural uranium reactors (UNGG), as well as other reactors, notably experimental reactors. This analysis is based, in particular, on local investigations in order to evaluate the conformity of these sites with the geological and environmental choice criteria"*. This disposal must also be designed to accommodate *"radium-bearing waste whose mass activity is such that it does not allow its disposal in a surface centre."*
- In conformity with the decisions taken by the Atomic Energy Commission (CEA) of 20 May 2008, Andra will address the National Public Debate Committee (CNDP) to organise a public debate early in 2011 before the Government decides on the site. After this choice, studies will be pursued to elaborate the authorisation application for the creation of the disposal.

38 Decree no. 2008-357 of 16 April 2008

39 Evaluation report released in June 2008

For the IL and HL/ -LL waste, the various milestones are :

- **31 December 2009 at the latest :** ″Andra proposes to the ministers of energy, research and the environment studies which it intends to conduct on the possible evolutions in the storage of high or intermediate level and long lived waste.″
- **31 December 2009 at the latest :** ″Andra proposes to the ministers of energy, research and the environment
- a limited zone of interest favourable for the installation of a disposal on which deep exploration techniques will be implemented ;
- design and long-term operational safety and reversibility options ;
- a waste inventory model to be taken into account ;
- storage options as a complement to disposal.″
- **31 December 2012 at the latest :** ″Andra submits to the ministers of energy, research and the environment the support file for the organisation of the public debate″, which will take place before the filing of an authorisation application for the creation of a deep geological repository site″.
- **31 December 2014 at the latest :** ″Andra files the authorisation application for the creation″ of a deep geological repository site.
- **31 December 2012 at the latest :** CEA submits to the ministers of energy, research and the environment a report providing an assessment of the research on separation-transmutation. This report will allow evaluating :
- *″a) the contribution of the recycling of the minor actinides and their transmutation with respect to their disposal within the vitrified waste ;*
- *b) the various imaginable recycling modes (heterogeneous, homogeneous) ;*
- *c) the possible associated management routes (new generation critical generating reactors, sub-critical accelerator driven reactors).″*
- *″This report should allow proceeding with an evaluation of the industrial perspectives of these management routes and making choices related to the facility prototype prescribed in article 3 of the Act of 28 June 2006″*[40].

Moreover, the fundamental evolution of the upcoming years in the nuclear energy field will reside in the consistency of the choices in terms of the fuel cycle and reactors. Based on this, it is also worthwhile to recall some timetables which, if they are not a part, strictly speaking, of the timetables concerning radioactive waste, are however crucial timetables for 4th generation reactors and are therefore indirectly part of the reflections on waste.

For R&D work on 4th generation reactors, a strategy was defined by the Atomic Energy Commission on 20 December 2006 and was confirmed by that of 20 May 2008. A first study phase is being pursued over the period 2007-2012.

After a consolidation scheduled for 2009 on given orientations, the conducted work is aimed at ensuring that a feasibility review can be held in 2012 which should allow making an assessment with the perspective of deciding for the gas solution or the sodium solution (with four main elements in the dossier 2012 : safety, economy, cycle, industrial perspectives).

1.2. June 2009 assessment of the studies conducted within the framework of PNGMDR 2007-2009

a. Research on conditioning and waste behaviour

Studies about long-term behaviour and demonstration of package performances in the retained long-term management method are part of the perimeter of the research regulated by the Act of 28 June 2006. However, except for the case of waste products before 2015 and still not conditioned, research on the conditioning of radioactive waste is no longer regulated by this same act.

40 It is here the 4th generation prototype reactor.

With the common objective of disposing of all the knowledge elements required to judge the acceptability of the waste packages in a disposal facility, the waste producers and Andra have set up control and exchange structures to guarantee the consistency of all the R&D programmes which they conduct individually or jointly within the framework of the responsibilities which they must assume. The R&D organisation set up in accordance with the Act of 28 June 2006 allows taking into account the new responsibilities of each of the players. It delegated the responsibilities of the producers with respect to the characterisation of the packages and the studies on the intrinsic behaviour of the packages, and the responsibilities of Andra with respect to the interactions between the packages and the surrounding materials.

In its first report of June 2007, the National Evaluation Committee (CNE) had observed that the inline conditioning of the current waste products is industrial and that there exist ways to envision the primary conditioning of all the waste. It emphasizes, however, that the conditioning in industrial primary packages, a key element in waste management, must continue to be considered with sustained attention.

Vitrification which has been implemented successfully for several decades in the plants of Marcoule and La Hague is today in France the industrial reference process for the conditioning of fission product solutions originating from reprocessing spent fuels (HL-LL waste).
Performance estimations of the R7T7 glasses in the deep geological repository are based on an operational model (called the ″V0→Vr model″). Experimental studies on leaching coupled with fine observation techniques confirmed that the residual velocity Vr which predominates over the long term is controlled by two main phenomena : the reactive diffusion of the glass elements through the alteration gel and the precipitation of secondary phases, in particular, phyllosilicates.

On the other hand, research on the effect of increasing the actinide content in the glass demonstrated good glass behaviour under alpha self-irradiation with, in particular, no glass change associated with the generation of helium originating from the decay of the actinides for doses reaching at least 1019 α/g, which corresponds to the integrated dose at 10 000 years. On account of this result, the Nuclear Safety Authority (ASN) granted at the end of 2008 the authorisation for the production of this package, which allows AREVA-NC to vitrify all the lots of fission product solutions without increasing the number of packages produced per tonne of processed fuels.

Several experiments intended to represent the glass's behaviour under disposal conditions (interfaces with steel and/or clays) were initiated and some of them are being analysed.

Finally, a new vitrification process implementing a cold crucible was developed by CEA. This process will be tested at the industrial scale by AREVA at La Hague beginning the end of 2009 for an industrialisation in 2010.

For the IL-LL waste, the hydrogen coming from the radiolysis of the organic materials is the gas released in the greatest quantity by the packages during the disposal's operation period (Andra dossier 2005). An R&D programme aimed at enhancing the modelling tools to predict the production of hydrogen and identify the productions of water soluble molecules - produced by polymer degradation – liable to complex radionuclides was set up. It will lead to the creation of a database (PRELOG) on the intrinsic data related to polymers which, when coupled with modelling, will allow evaluating the gas production yields from the main polymer composition data (chemical formula, load, additive, etc.) and the radiation spectrum.

b. Research on the deep geological repository

The project's development plan describes how the studies and research to be conducted over the period 2007-2015 will be conducted to satisfy the objectives fixed by the Act. It was presented in 2007 to the Parliamentary Office for Evaluation of Scientific and Technological Options (OPECST), the National Evaluation Committee (CNE), the Permanent ″Waste″ Group of the Nuclear Safety Authority (ASN) and the Local Committee on Information and Follow-up (CLIS). A summary of this document was also disseminated to the general public. The HL-LL waste project set-up phase was completed in 2007 with the finalisation of the thematic programmes, the detailed planning of the project, the set-up of the contractual framework and the start-up of the studies.

The first data available after the exploration campaign 2007-2008 reinforce and clarify the geological model of the sector and confirm the limits and the characteristics of the transposition zone such as they are described in the Dossier 2005. The physico-chemical characteristics of the formation of the Callovo-Oxfordian argilites do not allow obtaining at this stage any discriminating criteria to define a perimeter for the Zone of Interest for Depth Exploration (ZIRA). On the other hand, some geometric characteristics (thickness, depth, dip) are objective choice elements. Even though the safety parameters will always remain top priority, the ZIRA choice criteria could be consolidated with the local players before the deadline of the end of 2009. Moreover, this ZIRA will be associated with one or more surface installation scenarios.

The analysis of the earthquake profiles and the results of the exploration campaign will help improve understanding about the tectonic phasing and the movements of the associated faults since the Jurassic period up to our days. The various diagenetic phases affecting the surroundings, as well as their consequences on the transfer properties, are also described better.
In the underground research laboratory, besides the preparation of new experiments, a decrease notably of the convergence speeds was observed in the various structures.

The thematics linked to the transfer of radionuclides benefited from a significant contribution of knowledge coming from the European project FunMig, which was completed at the end of 2008. In particular, the following should be noted : the measurement of the void rate accessible to various molecules, the diffusive behaviour of organic molecules or the distribution of iodine in the formation of the Callovo-Oxfordian in order to define the retention capacities of the argilites. For the migration of the gases, the gas entry pressures in the argilites were determined and the behaviour of the gas at the interfaces studied.

Concerning the materials, the evolution of the concretes permeability as a function of the state of fissuration and the applied stresses, as well as the nature of the concrete/clay and steel/concrete interfaces, were studied. In parallel, research on corrosion rates in a disposal situation (fluids, clayey environment, etc.) was conducted.

c. Research on storage

Andra finalised in 2007 the storage related study programme. This programme relied on the transfer of knowledge realised with CEA in conformity with PNGMDR and on the reviewers recommendations. The main deliverables for 2009 concern the reporting of storage needs in connection with the updating of the national inventory of radioactive materials and waste and the proposal of options in terms of storage.

Among other things, thanks to its feedback, Andra identified the decisive processes with respect to the sustainability of the storage sites and the stored packages to conduct the engineering studies and research programming in the best possible way. In particular, it has now been acknowledged that the sustainability and the robustness of a storage over a century will depend on :

- the control and maintenance of the internal environment under dry conditions by means of notably design provisions linked to the processing of the air ;
- a choice of adapted materials, especially stainless steels for zones potentially exposed to corrosion, specific formulations of concretes to minimise atmospheric carbonation ;
- design solutions attenuating the various internal or external strains and stresses.

d. Research on the disposal of radium-bearing and graphite waste

Due to the low mass activity of radium-bearing and graphite waste, research was conducted on the options of shallow depth disposal (i.e. less than 200 metres) installed in a geological layer of low permeability with a dominant clayey or marly component. Two design options were studied and compared. The first option, called "disposal under a recast covering" (SCR), consists of using the open pit excavation technique to access the disposal ; after the waste is disposed of, the disposal zone is backfilled with the site’s broken muck. The second option, called "disposal under an intact covering"

(SCI), consists of using the subsoil digging technique. From a technical viewpoint, the second option allows exploiting fields of greater depth than the first and significantly extends the choice of possible installation sites.

Pending the identification of a site, these various options were studied based on realistic characteristics of generic sites coming from bibliographic studies.

The option of a disposal under an intact covering is privileged for graphite waste. In fact, the greater disposal clay thickness delays and attenuates better the flux of radionuclides liable to rise to the surface. For carbon C14, it is necessary to specify the retention capacities of the concretes, on the one hand, and the kind of carbon (organic or inorganic), on the other hand. For chlorine Cl36, it migrates mainly by diffusion, and its dispersion and spreading out over time will depend on the disposal layer's thickness.

For radium-bearing waste, a barrier to hinder the transport of solutes is less necessary because they are characterised by a radiological content and a lower activity. Also, the study of both design options under a recast or intact covering is being pursued for radium-bearing waste.

e. Modelling and simulation

In 2007, actions were initiated for the period 2007-2012 for the agency's modelling and simulation programme and for the consolidation of the Alliances platform's development plan.

Thanks to the work conducted notably with CEA during 2006 and 2007, much progress was made, including the implementation of new functionalities for transport in an unsaturated medium, the coupling of models of package degradation with the environment, the mechanics and the extension of the chemistry-transport coupling.

Other work allowed enhancing the qualification of the Alliances tool and its environment. Finally, concerted efforts were made to increase the computational capacities and the potential of certain codes (Porflow, Castem, Traces, Tough), especially to work on large mesh topologies.

In parallel, the work conducted within framework of the PACEN programme aims at grouping and interconnecting competences in mathematical modelling, numerical analysis and scientific computing, notably to satisfy the demands on the repository. Main efforts were applied to improving and consolidating the models for the site's hydrogeology, modelling the multiphase flows with gas production, and thermohydromechanical couplings. In particular, the introduction of a benchmark on gas transfer in the disposal by Andra and its development in connection with the NRG Momas should be noted.

f. Studies related to the separation and transmutation of minor actinides

The study of separation/transmutation takes place within a global nuclear waste management strategy. It will not concern the inventory of the IL and IL-LL waste which will be in the Dimensioning Inventory Model (MID) of the deep geological repository project, such as it will be presented in 2014 before the Parliament. Based on this, it complements the deep geological repository and its objective is to determine whether it can be a pathway to progress.

In this field, studies are still at the prospective stage and far from industrial developments. The implementation of such a technology can only be conceived for a distant date : it necessitates the existence of a new processing plant replacing the existing plant of La Hague and the presence of a number of 4th generation fast neutron reactors in the French installed base.

The objective of the current studies is to evaluate the industrial perspectives of the transmutation of the minor actinides, either in a critical reactor or in a sub-critical reactor (ADS : Accelerator Driven System) and to devise a research strategy for post-2012, notably via technico-economic study scenarios on the entire fuel cycle (what does transmutation bring with respect to transmuted cores ? which actinides to recycle ? in which forms of fuels or coverings ? And their implications on the fabrication of the fuels, their handling (loading and unloading), their transport and their reprocessing and the impact on the geological repository, etc.).

Even though the deadlines are long-term, it is necessary to prepare today because the qualification of fuels with minor actinides necessitates long R&D actions calling on experiments with irradiation ; the industrialisation of processing processes whose feasibility has been proven in the laboratory for some of them represents also a lengthy task. In addition, this work is indispensable to nurture reflective thinking on the design of reactors and plants of the future cycle.

For the assessment, the main results were obtained within the framework of the Act of 31 December 1991, under which the feasibility of the main separation options could be concluded. As for transmutation, the utilisation of fast spectrum reactors is the only imaginable possibility, but the technico-economic performances of the various scenarios still have to be affirmed as the design studies (reactor and facilities of the fuel cycle) go on. In addition, it should be noted that it is now known that transmutation will not concern the fission products, not even long lived ones.

g. Studies in the human and social sciences

In response to the PNGMDR (relayed by CNE), which requested CNRS watch over the pursuit of ″reflective thinking and studies in sociology and the human sciences″, the social sciences section of the CNRS's Sustainable Environment Department (EDD) organised in October 2007 a meeting during which it was decided to initiate beginning in 2008 within PACEN the internal CNRS activity programme called ACSSON (ACtion in Social Sciences On the Nuclear).

The information and dialogue approach proposed by Andra within the framework of the HL-LL project is presented in a document which describes the framework, the principles, the objectives and the phases of the programme. It was communicated to the Agency's institutional spokespeople (Trustees, CNDP, HCTISN, CLIS, Elected Officials). A concerted effort was also devoted to prepare exchanges with the local players for the definition of the future disposal centre's installation scenarios. The consultation approach relies on the integration of the human and social sciences within the Agency. This integration was taken care of by a newly hired manager who is assigned to the Scientific Management specifically for this task and the development of HSS studies associated with the project within the scientific programme's framework. In particular, it should be noted that a special programme was set up for ″reversibility″, which amounted to bringing together thirty participants for a work day and selecting a topic for a thesis funded by Andra.

2. Preparing for after 2012, a research strategy on the separation/transmutation of long lived radionuclides

The research programme on transmutation has several objectives :

- evaluate the contributions (and the potential detriments) resulting from a transmutation of long lived radionuclides (in particular, contributions to the disposal, in connection with Andra, on the plants of the fuel cycle, etc.) ;
- fine tune the processes of its implementation (separation, transmutation, fabrication of fuels and targets, etc.).

The targeted objective is to reduce the dangers and nuisances associated with long lived radionuclides in the ultimate waste : that is, essentially reduce the long-term radiotoxic inventory (1000 years and beyond) and the medium-term thermal load (a period of 100 to 1000 years), which is a dimensioning element of the repository.

The programme is only interested in the transmutation of the minor actinides except for the long lived activation or fission products present in the waste originating from reprocessing spent fuels. The minor actinides due to their very low mobility under the conditions of the studied geological repository contribute very little to the long-term impact. In fact, the results exposed by Andra in its Dossier 2005 reveal that the only real contributors to the radiological impact on the surface are iodine, chlorine and selenium, their incidence on the dose calculated at the outlet remaining low. On the other hand, the minor actinides are essential contributors to the thermal load of the waste for the period of a century and, based on this, are the main "target" of the research programme.

Neptunium (Np), Americium (Am) and Curium (Cm) present differentiated natures (for the nuisances that their presence causes on the waste, as well as for the difficulties induced by their recycling) ; therefore, it seems interesting to also study in a differentiated way the recycling of these various elements with the case of curium calling for notably an in-depth analysis.

The transmutation methods to be studied for the minor actinides concern their recycling in the homogeneous mode (in dilution in the fuels of the 4th generation reactors) or in the heterogeneous mode (in coverings or on dedicated targets) in the 4th generation reactors or in the accelerator driven systems (ADS).

2.1. Separation research

The processes under development concern essentially 3 major options :

- the recovery by an adaptation and complements to the PUREX process (or the COEX process) of neptunium, americium and curium present in the spent fuel [extensive separation – DIAMEX-SANEX processes] ;
- the recovery downstream from the COEX or PUREX process of only americium (the main contributor to radiotoxicity and the long-term thermal load of today's glasses) ;
- the global recovery of all the transuranians (plutonium and the minor actinides) [grouped separation – GANEX process].

Experimented processes on real solutions are already available for the first option (DIAMEX, SANEX) ; processes essentially related to the two other options of interest are to be developed and to undergo experiments at the laboratory scale by 2010.
The objectives of the R&D "separation" programme are :

- fine tune the processes for the recovery of minor actinides in spent fuels for the various studied management strategies ;
- and, with a view of an industrial transposition of these concepts :
    - simplify the processes as much as possible ;
    - consolidate their implementation.

For the industrial transposition, the R&D studies aim at simplying the schemes and acquiring the consolidations necessary for their implementation :

- *The "simplification" programme* aims at reinforcing their industrial viability based on the first concepts studied, notably by reducing the number of successive elementary steps and trying to operate at higher concentrations ; it began with the evolution of the formula of some extracting agents to respond better to these objectives. Two pathways are thus evaluated, a pathway combining in a single cycle the two processes DIAMEX and SANEX with a separation step for the extracting agents and a pathway using a new extracting agent called TODGA.
- *The "consolidation" programme* aims at better approaching all the aspects of the industrial implementation conditions of these processes by investigating notably the long-term performance evolutions, the command and control of the processes, the synthesis of reagents and the evolution of the sub-products, the development of simulation models of such processes (for in-depth operation analyses), etc.

These studies aim at having in 2012 the various elements required to evaluate the industrial perspectives called for under the terms of the Act of June 2006.

This research and these developments :

- are being backed by an *upstream research* conducted at the ICSM (Institute of Separative Chemistry of Marcoule – a joint research unit of CEA – CNRS – University of Montpellier) and through the PARIS NRG set up by CNRS via its interdisciplinary programme PACEN;
- are being conducted in conjunction with the development *of fuel or target fabrication processes* for the recycling of the recovered elements.

The studies on separation are being completed by research on *pyrochemical processes* with a more prospective application.

These processes considered compact offer assets, for example, for the processing of fuels hardly soluble in the aqueous phasey. Since their main interest resides in their low sensitivity to radiolysis, they should allow processing very high level radioactive fuels as soon as they unloaded from the reactor (for example, fuels for the ADSs).

The objective of the research on pyrochemical processes is to provide feasibility elements thanks to experiments in the laboratory and to move ahead in the evaluation of the issues raised by implementation at the industrial scale ; thus, efforts will be taken to ensure that a first series of experiments can be conducted in the laboratory on an irradiated object around 2012.

2.2. Fuel fabrication studies

After the separation phase of the elements to be transmuted, actinides conversion phases are necessary before the fuel is fabricated. The objective of the conversion is to obtain a solid compound from the nitric acid solutions of actinides originating from the separation processes.

The current R&D in progress aims at evaluating the various ways of converting the solutions loaded with minor actinides in order to identify the advantages and disadvantages of each of them. These results will allow orienting the choice of a potentially industrialisable process in 2012.

For the start-up cores (without minor actinides) of the prototypes to come, studies will be conducted mainly on the development of the MOX fuel. The feasibility of using a carbide fuel will, however, be evaluated integrating the fabrication, reprocessing and waste elimination phases.

For the MOX fuel, the main innovation emerges from the development of co-conversion. The R&D programme implemented until 2012 aims at developing U-Pu co-conversion up to the industrial stage and adapting the fuel ceramic fabrication phases to this new type of powder.

The fabrication facilities : Demonstration of the technological feasibility of transmutation necessitates access to fabrication tools of experimental fuels. These resources are necessary to produce the various fuel elements needed to supply the irradiation programmes which are indispensable not only for the development of the fuels and their qualification, but also for the development of the fabrication processes.
The purpose of the ALFA facility project under study today would be to produce when ASTRID goes into operation experimental needles loaded with minor actinides for experiments at the needle bundle scale (targeted capacity for ALFA : on the order of a kg of fuel per year).

In parallel, AREVA and CEA will jointly evaluate the feasibility and the cost of the construction on the La Hague site of a MOX fuel fabrication workshop for the ASTRID fast neutron prototype reactor.

2.3. Transmutation research

The objective of the studies conducted with CEA is to consolidate in 2012 the possible options for the transmutation of waste in the 4th generation critical reactor (fast neutrons), as well as in the sub-critical reactor (ADS). To evaluate the feasibility of the various transmutation options, which are not all today at the same maturity level, the following must be taken into consideration : fabrication of the materials, the handling of the fuels, targets or coverings, the impact on the reactor, the behaviour under irradiation and its modelling and finally the processing of the irradiated material.

- Homogeneous recycling of minor actinides : the minor actinides are incorporated in small proportions so that the impact on the core's safety parameters remains limited (typically a few %). In these proportions, the fuel's behaviour and performances are practically unaltered. This was demonstrated in the 1980s by the SUPERFACT irradiation in the PHENIX reactor. Since this option is the most mature option, the next step will be to demonstrate feasibility on several needles. This is the objective of the international programme GACID in the MONJU reactor conducted within the framework of the "4th Generation" forum. However, this irradiation could be imagined, depending on their availability and access conditions, either in other prototypes which will be available in the next decade or directly in the French prototype ASTRID. In the upcoming years, current knowledge will be enhanced by the advancements in modelling and the contributions from experiments conducted within an international framework (notably, irradiations with JOYO in Japan, and with ATR in the United States).

- Heterogeneous recycling of minor actinides : the minor actinides here are concentrated in dedicated assemblies positioned generally around the periphery of the core and, as a result, have practically no impact on the core's safety parameters. Two approaches are considered :
  - Recycling on an inert support (notably MgO), for which a large number of studies and experiments were conducted notably in the Phénix reactor. Post-irradiation examinations and the interpretation of these experiments will supply elements to consolidate the feasibility of this option in its two alternatives : multirecycling or monorecycling in a locally moderated environment.
  - Coverings loaded with minor actinides (CCAM) : today this is an approach which seems attractive and should be explored in priority by the National Evaluation Committee ; a concerted effort will be made on this topic, notably to have elements related to transmutation performances, the impact on the cycle, and the reactor's safety, in parallel with the preparation of the experiments ; the recycling is done on a uranium support (minor actinide content of 10% to 20%, with for an alternative the recycling of all or part of the minor actinides), which makes this option compatible with the reprocessing of the standard fuel *; however, a specific microstructure is to be refined and experimentally qualified*. An irradiation programme for the development of this fuel is being defined (essentially in the MTRs like OSIRIS, HFR (European programmes ACSEPT and FAIRFUELs), and then RJH before "integral" experiments in a fast neutron reactor.
- Recycling in a dedicated ADS reactor : the minor actinides are concentrated in the accelerator driven system (ADS) (typically 50%) and are then associated with plutonium. Some of the studies related to targets on an inert support are useful for fine tuning these dedicated fuels which are studied in an international framework. Irradiations are in progress, notably within the European framework in Phénix (FUTURIX-FTA) and HFR (BODEX and HELIOS), and the first results from post-irradiation examinations will be available in 2012, allowing a first approach on the feasibility of the ADS fuel. Moreover, CEA will continue its contribution to the acquisition of elementary neutron data and to the development of the proton accelerator (notably, injector, reliability test).

2.4. Technico-economic studies and scenarios

Technico-economic studies aim at having by 2012 elements to evaluate the costs to implement the various transmutation options studied for the installed electronuclear base and also to evaluate the consequences of the implementation of these options on :

- the deployment of the 4th generation reactors integrating notably the necessary resources ;
- the capacities of the cycle's facilities ;
- the waste produced and the surface it occupies in the geological repository ;
- the associated economic impacts.

The various families of studied scenarios and their associated alternatives will be complemented by means to quantify when the relevant parameters are available the contributions and detriments of these various options and to better understand the various possible deployment scenarios. CEA is conducting these studies in conjunction with the industrialists to support notably the choice of studied scenarios, the optimisation parameters and the evaluation criteria.

2.5. Upstream studies and nuclear data

Research in the nuclear data field is related to Orientation I of the Act in its section on transmutation. To do this, it must also integrate precision nuclear data needed for systems (critical or sub-critical) which could be conferred the task of reducing the quantities of minor actinides shipped with ultimate waste. The upstream and generalising nature of the subject matter facilitates the integration of the

French research activities (CNRS & CEA) in internationally coordinated programmes. Thus, the set-up work programme is determined by the conclusions of the OECD/NEA report. Starting from the characteristics of the 4th generation critical fast reactors (GEN-IV) and the accelerator driven systems (ADSs), this report defined a hierarchical list of isotopes (with the isotopes of americium and plutonium at the top of the list) and effective cross sections (fission, capture, reaction, nonelastic, total) for which current data are considered to lack sufficient precision (or are simply missing). In the extension of the European programmes EUROTRANS-NUDATRA, CANDIDE and EFNUDAT, the French teams have been integrated in a new programme of FP7 ANDES. Backed by accumulated experience and an international network of experimental facilities, the community is proposing to measure in the next three years at the required level of precision the effective differential cross sections taken from the OECD/NEA list. It will also implicate itself more actively in the evaluation process (uncertainties, covariance matrices) to accelerate the integration of the new results in the databases (JEFF, ENDF, etc.).

Finally, it will use these acquired differential data in the most recent simulation tools for a revisit of available results coming from integral experiments in a fast neutron reactor. This will allow appraising the adequacy for reactor physics of the elementary data's level of precision. Even though the covered energy field is to a great extent that of the thermal and fast critical reactors, a fraction of the work programme will also cover the relevant efficient cross sections (essentially cladding materials) for the highest energies encountered in the ADSs.

3. Enhancing knowledge and working upstream on waste conditioning

The producer is responsible for the production of the waste package and must give proof of the characteristics by creating a knowledge file and an operational model describing the long-term behaviour of this package. Upon request by the producers, CEA conducts an important part of the R&D required to implement the processes and enhance the knowledge of the conditioned waste's characteristics.

The approach to verify that the packages have the capacity to fulfill all the functions required for the disposal is responsibility of Andra, which created study programmes to determine the long-term behaviour of the various package families in the disposal environment. When there exist important couplings between the behaviour of the package and that of the surrounding materials or when the studies call on different scientific communities, R&D is conducted within a group of laboratories controlled by Andra. This is notably the case for the studies on the alteration of the glass and on the corrosion of the over-pack (group of ″glass / iron / clay laboratories″) and for those concerning the long-term behaviour of the concrete disposal packages (group of ″cement structures evolution″ laboratories). CEA participates in both of these groups of laboratories.

Current programmes are interested mainly in the following waste and package categories :

- the waste conditioned via the industrial management of the spent fuel such as practiced at La Hague ;
- the so-called "historical" waste stored at Marcoule and La Hague for the industrial reprocessing spent fuel before the start-up of the UP3 plant (1990) or that from the research activities of the same period. A part of this waste is still in a raw state or, in some cases, may necessitate a reconditioning. In conformity with the requirements of the Act of 28 June 2006, this operation should be terminated in 2030 ;
- the radium-bearing waste, originating mainly from the processing of the ores for the chemical industry ;
- the graphite waste, originating from the dismantling of the graphite moderated, gas cooled, natural uranium reactors ;
- the waste originating from the clean-up operations following the shutdown and that originating from the various deconstruction phases of the facilities ;

- the fuels from nuclear propulsion[41] and research reactors.

To ensure the consistency of all the studies on the long-term behaviour of the HL/IL-LL waste packages (data flow, planning, complementarity of the programmes, etc.), driving structures common to CEA, EDF, AREVA, Andra were set up.

For the graphite waste, R&D is driven within a joint structure uniting Andra, CEA and EDF.

Studies on spent fuels originating from nuclear propulsion and research reactors are conducted in the CEA – Andra partnership.

As a complement to the French reference way based on the processing of the fuel and as a conservatory measure, studies are also being pursued to increase knowledge about the long-term evolution of the properties of spent fuels from pressurised water reactors (REP), even though these latter are not considered to be waste. These studies are conducted in conjunction between Andra, CEA and EDF within the CEA programme PRECCI.

3.1. High level waste

Today, vitrification is the reference industrial process in France for conditioning high level waste. In connection with the start-up in 2010 of a ″cold crucible″ vitrification process in a vitrification line at La Hague, glass formulation studies are being pursued to take into account the evolutions in the compositions of fission product solutions and to process other types of waste, such as the effluents originating from the shutdown operations of the facilities and the solutions of fission products originating from the processing of Umo fuels UMo from graphite moderated, gas cooled, natural uranium reactors.

In the longer term, for the sake of rationalisation, studies (process and materials) aimed at extending the field of application of the vitrification will be pursued for certain effluents.

For the "current" glasses (R7T7, AVM, UMo), to progressively enhance the realism and robustness of the glass behavioural models necessary at Andra for the disposal studies, studies aimed at refining the knowledge of the alternation physico-chemical mechanisms will be conducted taking into account, in addition, the possibilities of evolution in the composition of the spent fuels (notably increased minor actinide contents).

There is an interest notably within the framework of an AREVA NC / CEA joint programme (2008-2010) in the problematics resulting from the initial fracturing of glass and its mechanical behaviour under disposal conditions. Within the framework of the group of ″glass / iron / clay″ laboratories set up by Andra, studies aim at, on the one hand, strengthening alternative glass mechanisms, but especially understanding and modelling the interactions between the glass and the other components of the disposal, on the other hand. In the first case, the glass's behaviour is to be prescribed taking into account the evolution of disposal conditions, such as the existence of an unsaturated phase, the interactions between the glass and the pore water of the argilaceous formation, or the possible role of microorganisms on the glass's alteration. Under these conditions, the relative importance of the various mechanisms responsible for the drop in the alteration rate will be evaluated.

In the second case, the interactions between the glass, the metallic materials and their corrosion products and the argilite are to be studied. To do this, an R&D programme was implemented integrating the experiments aimed at studying the mechanisms of these interactions, the integral experiments (also called the ″model″, such as the ARCORR experiments consisting of a vitrified waste in its metal envelope within the argilite under conditions close to those expected in the disposal) and the experiments in the underground research laboratory at Bure.

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41 Since the option of processing these fuels in the plant at La Hague is still under study, they are considered to be reusable materials and are included in the R&D programmes for long-term HL waste management only as a precaution.

Studies on the corrosion of the vitrified waste over-pack are conducted within the same group of laboratories. They aim at providing models and data which will allow dimensioning the over-pack. From this viewpoint, the research will be mainly oriented toward the determination of the corrosion rates depending on the disposal conditions (temperature, aerated or anoxic environment, argilite in contact or clayey water, etc.), the identification and characterisation of the corrosion products and the evaluation of the hydrogen production.

Studies on the alteration of the glass and the corrosion of the metal envelopes will necessitate understanding the interaction mechanisms of these materials with the argilite : nature of the corrosion products, interaction between the silicon originating from the glass and site water with the argilite, etc.

Finally, studies will aim at proposing less ″over-estimated″ models for the transfer of radionuclides outside of the glass and within the corrosion products.

This research will allow consolidating the behavioural models of the vitrified waste package ; the first version is expected for 2010 and the knowledge referentials for 2012.

3.2. Intermediate level waste

Studies on intermediate level waste aim at :

- reducing the volume of produced waste, in addition to the objectives of reducing the waste at the source ;
- obtaining a physico-chemical form of the waste as inert as possible, facilitating its future conditioning ;
- having conditioning methods for a better control of the produced waste packages, limiting the constraints for long-term and operation safety of the disposal.

Thus, the major issues of the upcoming years concern :

- decontamination :

Studies on liquid decontamination methods proven today and implemented in effluent processing stations are being pursued to reduce the quantities of reagents and chemical toxics in connection with the evolutions in regulations.
In the solids field, with the objective of reducing the quantities of effluents generated during these operations, the R&D efforts are directed on foam and gel formulation studies aimed at proposing industrialisable innovations in the 5 years to come.

- waste processing :

In addition to reducing the volume, waste processing aims at ensuring a compatibility, notably physico-chemical, between the waste and the matrix or the immobilisation system adopted to make up the package. The development of processing pathways for waste containing organic matter, notably technological waste (ion exchange resins, latex or neoprene gloves, etc.) or effluents (organic solvents, surface-active solutions, etc.) will be pursued.
For the organic effluents, hydrothermal oxidation by supercritical water (DELOS process) was placed in operation at the laboratory scale in the Atalante facility. Feedback should allow envisioning this process at an industrial scale.
For the technological waste, studies on the processing by plasma incineration / vitrification (SHIVA process) will be pursued with notably the increase of the torches lifetime, gas processing, etc. to ensure the pre-development of the process, moving to the industrial and power feasibility stage and within a decade decided for a deployment at the industrial scale.

- waste conditioning :

In the conditioning field, studies aim at extending the field of waste capable of being conditioned by cementation or vitrification, while preserving assets in terms of cost and implementation.
Considering the timetable fixed by the Act (conditioning of waste produced before 2015 at the latest in 2030), formulation studies on concretes for the conditioning of liquid effluents (rich in sulphates or borates, etc.) or solid effluents (waste originating from the uncladding of the UNGG fuels, graphite waste, etc.) will be pursued in connection with the needs of the producers.

A longer-term R&D on the potentialities of the materials such as siliceous aggregates and geopolymers for waste practically not compatible with the sodocalcic glass cements was launched.

Long-term behavioural studies on IL-LL waste will be conducted on three main thematics under the sub-groups of the technical committee of Andra / CEA / Producers.

- For the bituminised sludge packages, research aims at obtaining a better understanding of the production and release mechanisms of radiolysis gases in order to have a less over-estimated evaluation of the produced volumes, as well as to identify and quantify the release of organic species originating from the degradation of bitumens, which are potential complexing sources with respect to radionuclides. The potential impact of salts on the modification of the chemical conditions in the near field of the cells will also be evaluated, notably in connection with the experiments in the underground research laboratory. The data obtained in conjunction with the group of thermochemistry laboratories (thermochemical data on organic species) will allow simulating the consequences of the hydraulic and chemical disturbances induced by the bitumens at the cell scale.
- Gases originating from the corrosion of metallic materials and radioactive gases constitute the second thematic. Here, the production of hydrogen originating from the corrosion of the various metallic materials present in the waste is evaluated by studying the effect of saturation.
- The third thematic is devoted mainly to organic waste (other than bituminised sludge) to estimate the production of gas resulting from its radiolysis, and to identify and quantify the complexing and/or aggressive species originating from its degradation by hydrolysis and radiolysis.

For concrete disposal packages, the R&D engaged within the group of ″cement structures evaluation″ laboratories is not only a support for the formulation of hydraulic binders, but also aims at proposing long-term physical and chemical behavioural models integrating the coupling between chemical evolution and physical stresses (mechanical, thermal, etc.) and evaluating the possible interactions between the waste and the package (chemical, mechanical interactions, gas transfer).

3.3. LL-LL waste

Studies aim at understanding, on the one hand, the intrinsic behaviour of the waste package (producer's responsibility) and, on the other hand, the behaviour of the waste package in a disposal situation (Andra's responsibility).

In the case of graphite waste, the programmes are focused on the two most important radionuclides : chlorine 36 and carbon 14. For chlorine 36, its origin, its chemical form and its location must be known in order to quantify its release in the disposal. The purpose of the studies on carbon 14 is to make sure that it will be released in a non-gaseous inorganic form which is liable to be strongly trapped by the cement materials.

The objective is to devise an initial model covering the release of radionuclides by graphite for the preparatory calculations for the DAC and to detail the inventory in chlorine 36.

A part of the work directed on the thematic to learn more about graphite waste is mutualised at the European scale within the framework of the European Carbowaste Project (VIIth PCRD). Under this programme, alternative graphite management solutions by thermal processing will be explored, notably for the waste associated with 4th generation reactors.

Studies on ion exchange resins, which will be used to filter the water when some UNGG reactors are dismantled underwater, are being conducted by CEA and EDF in order to know their behaviour in a disposal (release of hydrogen by radiolysis and complexing species).

For radium-bearing waste, studies are focused on the speciation of radionuclides depending on the disposal conditions (clayey or cement medium) by integrating insolubilisation processes implemented by the producers. The effects of complexing species and salts from this waste on the transfer of radionuclides will also be evaluated.

3.4. Knowledge about the evolution of spent fuel

Today only a part of the UOX fuels is processed, and the MOX fuels are stored. The deferred reprocessing of these fuels is assumed to be consistent with the deployment of an installed base of 4th generation reactors, which will lead to industrial storage durations beyond current feedback. Therefore, more knowledge should be acquired about the behaviour of spent fuels (UOX and MOX awaiting reprocessing), and the evolution of the cladding and assembly under transport and extended underwater storage conditions.

Moreover, studies on the long-term behaviour of spent fuels which would be disposed of without any prior reprocessing (the influence of the site water composition and environment materials on alteration) will be pursued within the framework of a CEA-EDF-Andra partnership. These studies should allow creating by the end of 2010 a model for the release of radionuclides which will be less over-estimated than that retained for the Dossier 2005.

Studies on the fuels from nuclear propulsion systems and research reactors will benefit from those on the REPs for fuels in an oxide form. Specific actions will aim at determining the corrosion rate of the UZr fuels.

3.5. 4th generation reactor waste

Waste conditioning phases will follow the same logic as currently with the characterisation of raw waste, processing, conditioning and then placing in the container.

In the intermediate long term, the deployment of 4th generation reactors will necessitate processing on a larger scale the MOX fuels. It will be necessary to consider the impact due to the increase in the quantities of minor actinides and fines in the produced waste.

With as objective to reduce the quantities, the thermal load and the radiotoxicity of the waste, the fuel cycle associated with the 4th generation reactors will be modified with respect to the existent, and the waste originating from reprocessing future spent fuels will show differences. In fact, the fuel cycle and, therefore, the produced waste will be modified depending on the type of fuel and the recycling options for the minor actinides. The management of this waste will be examined with respect to the existing management routes in order to demonstrate its compatibility or to explore possible evolutions in the management routes (volatile element management, new conditioning processes with, for example, the reprocessing of some fuels by pyrochemical processes, consequences on the disposal's surface, etc.).

Finally, in the perspective of the construction of new reprocessing–recycling plants far from the sea (export projects, for example), trapping and conditioning of certain volatile fission products such as iodine will be examined.

4. Preparing waste storage and disposal projects

From a scientific viewpoint, the research actions conducted in order to prepare the implementation of the various storage and disposal facilities have points in common. For example, all the projects are interested by the work on the behaviour of radionuclides, the reactivity of the hydraulic binders or the improvement of the sequential interpretation from diagraphics. Therefore, in the following sections, we shall describe the research more specific for each project, as well as the actions to which particular attention will be paid during the period 2010-2012.

4.1. Storage

The research associated with the storage program, in addition to the aerological and thermo-aerological aspects, is essentially oriented toward the behaviour of the materials which would be implemented to construct the storage structures and, to a lesser extent, the packaging materials.

Upstream from the definition of storage concepts, it was decided to satisfy a need for knowledge about expected "generic" processes under storage conditions. This programme is designed to supply results on the various processes envisioned for 2011.

In the case of cement materials, a programme to study carbonation versus temperature in unsaturated media is intended to lead to the creation of an atmospheric carbonation vs temperature model. In parallel, experiments aimed at evaluating the creep of concretes vs temperature were defined and started on pluri-decimetric samples, as well as on the Galatée facility of Marcoule.

Studies on gaseous and aqueous transfers in unsaturated cement materials also correspond to the expected problematics under storage conditions over a century. They will be covered by work complementary to that performed within the framework of the HL/IL-LL disposal project.

In the case of metallic materials, a documentary analysis of the corrosion of metallic materials under radiation demonstrated the necessity of implementing a programme whose characteristics are still not clearly defined today.

The study of atmospheric corrosion complements the work initiated by CEA on this topic and which is currently being pursued with as objective to create a corrosion model. The current phase is the identification and quantification of the dimensioning parameters (description of the kinetics, corrosion facies, etc.). This work will be pursued in relation with that defined on corrosion in a carbonated cement medium (degraded by atmospheric carbonation). In addition to the kinetic characterisation of the processes and the definition of the extension of the zones physically and chemically impacted by the corrosion products, input data is to be supplied for the coupled corrosion/mechanics modelling for which the work of this programme must culminate.

As a complement to the laboratory experiments on corrosion/mechanics couplings, a programme to monitor the old industrial structures is under study.

4.2. Shallow depth disposal for low level and long lived waste

Even though many thematics are comparable to those developed within the framework of the HL-LL project (geology of the sedimentary stratum, alkaline stream, gas source term, representation of the transfers of many elements, etc.), the LL-LL waste disposal features a number of specificities : potentially different geological formations, possible presence of a recast covering, nature of the waste (graphite from UNGG reactors, chemical toxics, radon), possibility of an outcrop host layer, etc. Two specific points of the LL-LL disposal project deserve to be clarified and are hereafter.

a. The characterisation of the sites

The site exploration resources implemented from the surface will allow accessing data specific to the sites (topography, geological cross section, geotechnical and hydrogeological characteristics of the formations, etc.), as well as the samples necessary for the characterisation of the physico-chemical properties. A special analysis will be performed to select the geophysical methods capable of providing detailed information about the surface formations, as well as to interpret the obtained data.

Knowledge about the geological context should allow determining the volume which is available in the potential host formation, as well as some of its properties, such as its capacity to delay the migration of radionuclides or its ability to create the disposal's infrastructures. The surroundings of the host layer will also be characterised in order to create a hydrogeological scheme and to contribute to the building of an overall geological model.

In the case of an SCR disposal (Disposal under a Recast Covering), the host formation has an outcrop. Yet, freeze – unfreeze cycles, contact with oxygen or trickling water are phenomena which are liable to alter the surface clays. Therefore, it is necessary to estimate the impact of the resulting physical and chemical modifications.

On these bases, studies on the natural evolution of the geological medium must satisfy three main objectives for the evaluations of safety :

- analyse the risk of a disposal erosion (SCR, in particular) ;
- estimate the modifications of the underlying surroundings, such as the creation or development of karsts ;
- characterise the physical components of the typical biospheres possible in the future.

b. Chemistry and migration of radionuclides and priority chemical toxics

In the case of radium-bearing waste, preliminary generic calculations indicate that the priority radionuclides are associated with the radioactive relationship routes 4N+2 (Ra 226, Pb 210, Th 230, U 234, U 238) and to a lesser extent 4N+3 (Pa 231, Ac 227, U 235). In the case of actinides, the oxidation-reduction conditions should be controlled within the disposal and its geological environment (SCR in particular). Radium-bearing waste is also characterised by chemical toxics (As, B, Hg, Sb, Cd) on which the relevant transfer parameters will have to be determined for the safety analysis and the impact study.

In the case of graphite waste, three radionuclides cover for the most part the radiological spectrum associated with the release of the inventory of graphite underwater : Cl 36, Ca 41 and C 14, previous work showing that the main contribution is associated with Cl 36.

The behaviour of Cl 36 is controlled by its diffusion within the disposal materials (very low sorption in the cement materials) and the geological formation (anionic exclusion and absence of a chemical delay in the argilaceous rock). Therefore, particular attention will be paid to verify these tendencies and, if necessary, to search for cement materials optimised with respect to Cl 36 trapping and to adapt the specific chlorine transfer model in the biosphere by integrating the dynamics of change in the Cl-36/Cl ratio in the soil.

The processing of C 14 will be aimed at defining a generalised behavioural model in consistency with the forms released by the graphites. A distinction will be made between the organic and inorganic species. For the organic species, diffusion measurements may be taken as a complement to those in progress for the HL-LL project. For the inorganic species, the isotopic exchange within solid carbonates will be evaluated by quantifying notably the accessibility of the carbonated fraction within the total rock. All the tests should lead to a model connecting the overall steric dimensions of the molecules with the connectivity of the pore network characterising the intact rock. For Ca 41, the representativity of the exchange coefficients defined for the argilaceous fraction in the intact rock will be verified and then the isotopic exchange will be evaluated, in particular, on the carbonated fraction.

Aside from the aspects linked to the transfer of radionuclides, the presence of salts and notably nitrates and sulphates originating from the radium-bearing waste raises upstream research problematics linked to the transport of solutes, such as osmotic overpressures, the existence of an anionic exclusion phenomenon within the host rock or the co-diffusion of radionuclides and chemical toxics of interest.

4.3. Reversible deep geological repository for high or intermediate level and long lived waste

The implemented scientific programme is founded on an operational structure constructed around reflections made until mid-2007 and leading more specifically to the implementation of programme units, including an important part based on an operation in groups of laboratories. It also relies on the renewal of most of the partnerships of the Agency and the updating of the scientific research topics feeding their activity.

a. Preparing the disposal's installation

After the selection of the Zone of Interest for Depth Exploration (30 km2), exploration resources will have to be implemented as of 2010 to allow defining with precision the geometry of the layers, their arrangement, and the properties of the rock composing them.

The acquisition and processing of the high resolution 3D earthquake data will aim at, in particular, reinforcing the interpretations on the structuring of the sedimentary pile, ensuring the absence of tectonic structures in the layer of the Callovo-Oxfordian and having a 3D vision of the distribution of certain properties of the layer and its surroundings.

A 3D geometric modelling of the layer will also be available at this stage, which will provide the framework necessary to propose more precise installation options for the disposal.

b. Implementing the observation and monitoring resources

The observation of the surface environment will aim at not only supplying regulatory data for the initial condition of the site, but also understanding the dynamics of the media for the impact study and the dimensioning of the monitoring of the environment during the construction and operation of the disposal. The Perenne Observatory for the Environment (OPE) aims notably at coping with the issues linked to the observation/monitoring duration of the disposal. It envisions, in particular, a data management and a preservation of the samples to keep a record of the reference situation through the creation around 2012 of an eco-library on the Meuse/Haute-Marne site. This sample base guarantees the traceability of the environmental measurements taken over a period on the order of a century. The eco-library will accommodate all the links in the alimentary route : water, soil, plant, animal products. Andra will be in charge of its design, its construction and the equipment with an adapted infrastructure (cryogenics, etc.), as well as its operation over time. Besides these objectives, the ambition is to make available to the scientific community relevant and qualified data and an instrumentation.

The observation / monitoring of the structures and notably those of the cells should allow following their phenomenological evolution and providing knowledge to support the management of a reversible disposal. It amounts to being able to re-evaluate the lifetime of the structures and also providing the elements required to evaluate the possible removal conditions of the disposal packages.

In this context, the selected measurement resources must take into account the specific constraints of a disposal. Among them, discretion (miniaturisation, wireless communication) and robustness (sustainability in a hostile environment, autonomy) are the objectives which support the implemented R&D. In particular, it is intended to :

- guarantee the availability of the measurement resources, notably the chemical and radiological measurements in a practically inaccessible environment ;
- develop distributed measurement resources in response to the difficulty of identifying *a priori* the location of important evolutions ;
- develop data analysis and interpretive tools and modellings to support the monitoring strategy;
- increase the robustness, reliability, sustainability and discretion, reduce the consumption or increase the energy autonomy of the monitoring resources (″hardening″) ;
- qualify and certify the resources and the monitoring systems by tests and demonstrators.

A part of the R&D will be accomplished within the framework of the European monitoring project ″MoDeRn″, which will take place within the framework of the 7th PCRD, with Andra as the coordinator.

c. Developing experiments and demonstration operations integrated in the underground research laboratory

The experiment and demonstration test programme in the underground research laboratory defines the priorities which are based on the needs of the HL/IL-LL project and integrate the possibilities of developing the laboratory's architecture offered by the renewal of the laboratory's authorisation beyond 2011. In particular, the following objectives should be retained :

- enhanced knowledge of elementary phenomena (Experimental Drift Two) based on experiments aimed at completing the knowledge on thermohydromechanical behaviours, desaturation - resaturation and gas transfer. Data will also be acquired in situ and over long periods on the interactions between the disposal materials (glass, steel, hydraulic binder) and argilites ;
- fine-tuning of the digging method for HL waste disposal cells (Drift Research & Methods). This corresponds for the period 2010-2012 to the implementation of more and more integrated tests which allow specifying the hydromechanical and then the thermohydromechanical behaviour of the structures and validating and optimising the construction techniques ;

- digging tests with the road header (Experimental Drift Three) and non-arched ground supports (Flexible Design Drift, Rigid Design Drift). This will allow specifying according to the digging techniques, the hydromechanical behaviour, the formation and the evolution of the EDZ.
- preparatory testing for the drift seal test (Experimental Drift Three), making the seal (Seal Test Drift). The EDZ in situ evolution will be characterised under mechanical stress in connection with permeability.

In parallel, the closing tests of the HL cells allow testing the technical implementation and performance of the gas and water plug. Starting from 2012, an implementation and performance test which is expected to last for several years will be initiated on a seal (core) in the drift.

The 2009 milestone of the HL/IL-LL project, which includes an optimisation of the technical concepts of underground structures, also allows specifying certain objectives of the demonstration tests in the underground research laboratory. Thus, the second phase of technological tests on HL cells may take into account the retained provisions.

4.4. Targeting scientific progress in support of storage and disposal projects

Some research and development actions are common to the various projects. They are intended to provide scientific bases which are essential to understand the processes and their representation, as well as the reuse of this acquired knowledge, in order to make choices in terms of the architecture and dimensioning of the disposals and storages. Two examples are given hereafter.

a. Pursuing the implementation of high-performance simulation resources

With the objective of having computing tools which are qualified, high-performance and controlled (methods, codes and machines) available, the development of the Alliances platform will be finalised. The Alliances orientations for progress concern mainly the representation of the processes and the analysis methods applied to specific processes. They are completed by the Alliances enhanced ″ergonomy″ (for example, the Man/Machine Interfaces) which is necessary for a supported and shared utilisation of Alliances, notably to define the calculations and then interpret the results (pre- and post-processing), as well as some computing functionalities, such as memory management.

The creation of simulation strategies adapted to each problem must also be pursued, taking into account notably the state of knowledge and the capacities of the available tools : for example, the link between the site and the regional scales for hydrogeology or the transition from the local source to the cell scale, and then from the disposal module and finally the geological medium for the hydraulic – gas transient.

Thus, at the projects different deadlines, the Alliances platform should allow covering in the best possible way the requirements in finesse, completeness and precision for the phenomenological representations, such as envisioned or imaginable for the preparatory calculations and, finally, the impact calculations. The simulation resources must also be designed to serve as an aid for design and reversibility options.

Efforts oriented since 2007 toward the representation of processes implemented during the disposal's operation and in its reversibility phase will also be pursued.

Finally, to conduct complex time-space simulations, "high-performance" computational needs will be evaluated, which constitutes a possible response to the future requirement for a still more intimate knowledge about how disposals and storages function.

b. A fine modelling of the structure and reactivity of argilites

The intimate knowledge about the pore structure and solid – fluid interactions, for example, free water/bound water/interfoliaceous water, liquid water/gas/argilaceous minerals, are at the core of the understanding of the hydraulic, geochemical and mechanical behaviours of natural clay media, as well as the transfer and speciation of radionuclides in solution. The progress made these last few years experimentally with nanotomography and with ab initio and molecular modellings opens perspectives in terms of the possibility of a multi-dimensional and multi-scale description (from nano to pluri centimeters) of natural clay media. These developments based on the sum of knowledge acquired on the various Andra projects should lead to a behavioural model of almost impermeable argilaceous rock.

5. Research conducted in support of the safety appraisal of the deep geological repository

IRSN has organised to produce on time the appraisals of the safety files which will be presented by Andra for the creation of new radioactive waste disposal facilities. Among the fields justifying such a concerted research effort is that of safety in a deep geological repository. IRSN research activities on this topic are positioned differently from those for which Andra is in charge. Mobilising more limited resources, they are focused on a restricted number of targeted subjects aimed at independently providing the support required for the coming appraisals. IRSN plans for the period 2009-2012 to explore especially the following fields :

- **about the important characteristics for the confinement capacity of the geological barrier :** in addition to the analysis of the ground data related to the Andra studied site and the evaluation of the limits of the exploration methods used, the Institute will concentrate, in particular, its efforts on studying the differential fracturing of the clays, which aims notably at providing explanatory elements concerning the presence or absence of fracturing in the various argilaceous formations. IRSN studies related to the confinement characteristics of the geological medium are notably conducted within the NRG Trasse (associating IRSN and CNRS), as well as the ″Mont Terri″ project.
- **about thermal, hydric and mechanical (THM) phenomena :** liable to affect the performances of the disposal's components, IRSN will essentially concentrate its efforts during the next three years, on the one hand, on the numerical modelling of the creation processes of the fractured zone around structures during their digging (EDZ) and, on the other hand, on the preparation of experiments in the Tournemire experimental station (see hereafter) aimed at appraising the key parameters which govern a seal's global performances. Another development orientation concerns the understanding and modelling of the effects of gases in a disposal. IRSN is contributing on this point to the European project Forge (cf. international annex), notably for the evaluation of the gas formation mechanisms and the numerical simulations of the expected effects,
- **about the main physico-chemical evolution factors of the disposal's components :** engaged studies aim at determining the influence on safety of the chemical processes during the various life phases of a disposal. The Institute will place emphasis notably on the study of the possible effects of bacterial growth on the corrosion of steels, on the study of the phenomena of radiolysis and degradation of waste packages, and on the understanding of complex cement/iron/clay chemical interactions by means of experiments in the Tournemire experimental station conducted within the framework of the NRG Trasse,
- **about global modelling of the disposal** : specific Institute efforts will be assigned to evaluating the influence of the hydraulic schemes of the Meuse/Haute-Marne site using its own hydrogeological models, as well as developing and simulating the transfers of radionuclides in the geological medium by means of the computational code MELODIE (participation of the Institute in the 6th PCRD projects Micado and Pamina, as well as the NRG Momas).

IRSN research is not an isolated research initiative. In fact, many cooperations are already engaged with a network of renowned scientific partners (CEA, ENTPE, ENPC, ENSMP, LCPC, INERIS, IFP, CGG, CEREGE, the French universities of Paris VI, Orsay, Pau, Nancy, Grenoble, etc.). The Institute makes available to its network of partners its experimental resources, in particular, the experimental station in the argilaceous medium of Tournemire in the Aveyron department, integrated since 2007 in the network of IAEA centres of excellence. Finally, recall that IRSN signed a memorandum of understanding (MOU) with Andra to conduct common research actions according to provisions to respect the necessary ethics rules.

6. Studies in human and social sciences

6.1. Academic research on the nuclear

As expressly demanded in the 2007 PNGMDR edition and by the Scientific Council of the CNRS, the PACEN programme is devoted to the development of its research component in the field of the social sciences (ACSSON). A priori, it has the task of covering all the society's issues concerning the civil nuclear sector. The tackled topics go far beyond the traditional issue of the radionuclear risk and how it is perceived by the public. A spectrum of topics were thus evoked among which foreign experiences both for the civil nuclear as a component of the nuclear power production system as for the social problematic of the management of the waste generated by this production. The player communication methodologies (pro or con), the meaning of a nuclear said to be ″sustainable″, the evaluation of the benefits from transparency, and the specific aspects of French and international law are topics which also deserve consideration. Finally, it would be important to review all the studies of an economic nature in the widest sense, that is, including the environmental impacts. Therefore, there is a wide variety of topics for which a reflection by the social science community would be extremely enriching for the PNGMDR's research programme.

To take into account the operating modalities of the HSS community, which is fragmented and modestly structured, it seemed more effective for PACEN to avoid trying to hierarchise the topics on which an action would be initiated. Rather, a broad and undifferentiated exploration was instituted to identify one or several researchers who would agree to bring a relevant project. They are left the possibility to vary the topic and organise a seminar or any other form of activity. Therefore, PACEN is committed to leaving the players the greatest degree of freedom to define the format of their action. Once a certain ″critical mass″ is reached, an attempt will be made, if possible, to structure the actions which it will have been possible to initiate as a consistent whole. Initially, therefore, ACSSON will be more an envelope of juxtaposed actions than a unified programme.

At the end of 2007, ACSSON organised a seminar on the topic of temporality versus the nuclear. The conclusions of this seminar will be reported in 2009. The topic entailed analysing the way in which the long nuclear time scales ranging from a decade to hundreds of thousands of years can be assimilated by a society whose evolution rates range rather from a few months to a political office term. The year 2009 inaugurated an ALIEN seminar on Germany. During the first year, ALIEN will study how the ideas on the civil nuclear have evolved in Germany since the end of World War II up to today's situation and the implementation of the ″get out of the nuclear″ doctrine. The year 2010 will be devoted to analysing the energy and climate dilemmas associated with the present situation and the ways of possibly resolving them. An action on legal rights and the nuclear is currently in preparation.

6.2. Supporting a reflection on long-term solutions

By defining its research policy in the human and social sciences (HSS), Andra aims at notably interesting HSS researchers in the work of Andra and progressively mobilising this community around topics of common interest. The thematic of reversibility was chosen for this reason and initially in order to incorporate social aspects in the design of the future disposal centre and to favour exchanges with the recipients.

Research topics specifically oriented toward HSS are regularly proposed in the Andra doctoral theses allocation programme as the economic approach of reversibility, a topic which is already under study for a doctoral research programme.

Based on a study day organised around this topic on 2 October 2008, Andra scheduled an interdisciplinary colloquium in June 2009. By extending reflections to other fields (GMOs, nanotechnologies, climatic reheating, etc.) and other comparable industrial experiments, this colloquium is planning to publish a reference work on the issue and prefigures the international colloquium of the NEA/OECD scheduled for 2010.

Andra would like to consolidate this community of interest between the HSS and the Agency around reversibility before extending the list of thematics to be treated and the possibilities of collaboration.

Nonetheless, it is already envisioned to deal with the issue of the preservation of the memory of the sites in the same spirit as of 2009-2010.

From a long-term perspective, the role of mediation between the technique, politics and the social that Andra is dedicated to playing in order to develop an expertise with a political finality should be examined in a reflexive way. The strategic orientation of the organisation will therefore be a topic for a very important investigative endeavor in the near future for which the HSS community's contribution seems vital.

In addition to the aforementioned research strategy and with a more operational objective, occasional studies were also proposed within the catalogue of scientific programmes for the HL/IL-LL and LL-LL waste projects. These studies dealt with issues ranging from the perception of risks to their society-based consequences, from the development of territories to the consultation modalities, or from temporality to management over long time scales. Less directly oriented toward research, they aim mainly at collecting information and elaborating advice for the Agency with respect to the present day situation of the various projects.