French National Plan

for the management of Radioactive Materials and Waste

2016 – 2018

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Foreword

Radioactive materials and waste must be managed sustainably, to protect individual health, safety and the environment. Attempts must be made to mitigate the burden to be borne by future generations.

The National Plan for Radioactive Materials and Waste Management (PNGMDR) is a key tool in ensuring the long-term implementation of these principles, within the framework set out in the Environment Code and in the 28th June 2006 Act on the sustainable management of radioactive materials and waste. This plan, which is updated every three years, reviews the management policy for radioactive substances nationwide, identifies new requirements and determines the objectives, more specifically in terms of studies and research into new management solutions. The strength of the PNGMDR is its comprehensiveness: it concerns both ultimate waste and reusable radioactive materials, existing management routes and those planned, under development or to be defined. It also concerns all categories of radioactive waste, regardless of its origin. The interest of this approach was confirmed at the European level by Council directive 2011/70/Euratom establishing a community framework for the responsible and safe management of spent fuel and radioactive waste, adopted on 19th July 2011, which requires generalised adoption of such an approach. Finally, this new PNGMDR also incorporates the guidelines of the Energy Transition for Green Growth Act.

For this new edition of the PNGMDR, the fourth since 2007, we have sought to take account of operating experience feedback as well as comments made regarding the previous versions of the PNGMDR, in particular those from the Parliamentary Office for the evaluation of scientific and technological choices. The General Directorate for Energy and Climate (DGEC) and ASN have, with the successive editions, sought to continuously improve both the presentation and the content of the PNGMDR. All and any suggestions from the readers enabling the Plan to be improved and made clearer are therefore naturally welcome.

In order to build confidence, transparency and high-quality information are crucial. Similarly, dialogue and consultation, especially with the representatives of civil society, must also be central considerations when drafting public policies.

The DGEC and ASN thus chose to draft the PNGMDR on the basis of the presentations and exchanges carried out within a pluralistic working group, more particularly comprising environmental protection associations, experts, representatives of local information committees and the regulatory authorities, alongside industrial players and producers and managers of radioactive waste. 53 meetings of this working group have therefore been held since 2003. We would like to extend our warmest thanks to all the members of this working group for their participation and to congratulate them for their contribution, the quality of which must be underlined and without whom the level of progress achieved in just a few years would not have been possible.

In order to guarantee transparency and in accordance with Article 542-1-2 of the Environment Code, the PNGMDR will be made public and will be available for consultation on the ASN and

DGEC websites. A more educational and informative summary will also be published so that the PNGMDR is accessible to the greatest possible number of readers. Pursuant to Articles L. 122-4 and following of the Environment Code, the probable impacts of the implementation of this new edition of the PNGMDR on the environment were also the subject of a strategic environmental assessment, for which the report and corresponding ASN opinion will be made available to the public with a view to ensuring the transparency of information. The 2016-2018 PNGMDR and its environmental assessment will thus provide an integrated overview of the issues and challenges associated with the management of radioactive materials and waste.

The PNGMDR proposes possible solutions for improving the management of all radioactive materials and waste. These proposals are the result of extensive work carried out since the first version of the PNGMDR covering the period 2007-2009, including in particular the performance and subsequent assessment of the studies required by the Government. Although much progress has been made, it is essential that the work be continued without interruption. It should be noted that under the polluter-pays principle, all this work will continue to be directly or indirectly financed by the producers of the radioactive materials and waste.

Even though radioactive materials and waste are now safely managed under the control of the nuclear safety regulators, we cannot over-emphasise how essential we feel that it is to implement the recommendations of this PNGMDR. New avenues for work are today open, in particular concerning the long-term harmfulness of radioactive waste from a more global environmental perspective, the prospects for long-term reutilisation of certain radioactive materials, or the storage strategies adopted by the licensees pending the availability of final management solutions. The answers to the questions raised will determine our capacity to avoid imposing the burden of managing these waste on future generations.

Introduction

When faced with the considerable diversity of radioactive materials and waste, it may be hard to grasp the pertinence and consistency of the management framework put into place. The National Plan for Radioactive Materials and Waste Management (PNGMDR) aims to clarify and improve this management framework. To do this, it reviews management policy, identifies requirements and determines objectives for the future.

The effectiveness of the PNGMDR has been confirmed by Parliament. The assessment report on the 2013-2015 PNGMDR by the Parliamentary Office for the Evaluation of Scientific and Technical Choices[1] (OPECST) thus welcomes “a more accessible PNGMDR that is better structured than its predecessors, even though it covers an even broader field”. It underlines “the continued progress made in the work done by the PNGMDR pluralistic working group” which contributed to the drafting of the Plan. Apart from the progress underlined, the report identifies a number of areas for improvement via recommendations concerning the organisation of the PNGMDR working group. A number of improvements aiming to encourage exchanges and consultation, as well as transparency and public information were initiated - in the light of the OPECST’s opinion - by the General Directorate for Energy and Climate (DGEC) and ASN. The steps already taken in this direction were therefore naturally continued.

The PNGMDR gives the general public an overview of radioactive materials and waste management. The main interest of the PNGMDR is thus its clearly stated goal of comprehensiveness.

Article L. 542-1-2 of the Environment Code defines the PNGMDR’s objectives more precisely: it “reviews the existing methods of radioactive materials and waste management and the technical solutions adopted, lists the foreseeable needs for storage or disposal facilities and specifies their required capacities and the storage durations. It sets the general targets, the main time-frames and the schedules enabling these time-frames to be met while taking into account the priorities it defines. It determines the targets to be met for radioactive waste for which there is as yet no final management solution.” This article also states that the PNGMDR “organises research and studies into the management of radioactive materials and waste, by setting deadlines for the implementation of new management modes, the creation of facilities or the modification of existing facilities […]", and that “it comprises an appendix summarising accomplishments and research in other countries".

The structure of the 2016-2018 PNGMDR was revised in order to give a more strategic vision of the management of radioactive materials and waste, reinforcing the issues relating to radioactive materials and presenting waste management according to the individual routes. The presentation of certain topics (management of decommissioning waste, management of materials, spent fuels, etc.) was also supplemented. The document is thus divided into four main parts. a presentation of the principles and objectives of the management of radioactive materials and waste, which includes a reminder of the legal and institutional framework; the review of utilisation modes and prospects

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[1] Report on behalf of the Parliamentary Office for Scientific and Technological Choices on the evaluation of the national plan for radioactive materials and waste management, 2013-2015 PNGMDR.

for the reutilisation of radioactive materials; the review and prospects for the development of existing management routes and the needs and prospects for management routes to be implemented. A number of appendices are included: a presentation of the studies carried out on the preservation of memory; a summary of accomplishments and research in other countries; a detailed presentation of the studies and research to be carried out in the coming years on the management of radioactive materials and waste; a presentation of concepts and plans for the period following closure of the repositories and the list of intergovernmental agreements concluded by France with other countries concerning the management of spent fuel or radioactive waste.

Note: The PNGMDR recommendations and indicators, numbered per chapter, are introduced during the course of the text and referred to by the following letters:

- R: Recommendation
- I: Indicator

1 Management of radioactive materials and waste: principles and objectives

1.1 Presentation of radioactive materials and waste

When dealing with radioactive substances, the Environment Code makes a distinction between radioactive materials and waste.

These substances are classified as radioactive materials when, owing more specifically to their radioactive, fissile, fertile or fusible properties, subsequent use is planned or envisaged. This is mainly the case with nuclear fuels, either active or spent, and natural, enriched, depleted or reprocessed uranium, plutonium and thorium.

If no subsequent use is planned or envisaged, then these radioactive substances are classified as waste. We talk of ultimate waste when a waste can no longer be processed in current technical and economic conditions.

With regard to radioactive waste, the usual French classification is based on two parameters: the activity level of the radioactive elements and their half-life. This classification comprises the following main categories:

- high level waste (HLW),
- intermediate level, long-lived waste (ILW-LL),
- low level, long-lived waste (LLW-LL),
- low level and intermediate level, short-lived waste (LLW/ILW-SL),
- very low level waste (VLLW),
- waste with very short half-life (<100 days), managed by decay and then eliminated in conventional routes.

The radioactive materials and waste produced since the beginning of the 20th century come mainly from five economic sectors: nuclear power generation, research, Defence, industry unrelated to nuclear power generation and the medical sector.

A National Inventory of these radioactive materials and waste is produced every three years by the French national agency for radioactive waste management (Andra). The 2015 edition identifies the materials and waste in existence at the end of 2013 and presents the forecasts for the end of 2020 and the end of 2030 as well as at the end of the service life of the existing NPP fleet.

1.1.1 Definitions

According to the Environment Code (Article L.542-1-1) "a **radioactive substance** is a substance containing natural or artificial radionuclides, the activity or concentration of which justifies radiation protection".

These radioactive substances may be classified as radioactive materials or radioactive waste depending on the subsequent utilisation planned or envisaged:

- “when further use is planned or envisaged, if necessary after processing”, the radioactive substance may be classified as a **radioactive material**[2];
- “when no further use is planned or envisaged”, the radioactive substance is classified as **radioactive waste**.

Furthermore, pursuant to Article L. 542-13-2, a radioactive material may nonetheless be reclassified as radioactive waste by the administrative authority, if its further use prospects are not sufficiently well-established.

Council directive 2011/70/EURATOM of 19th July 2011 establishing a community framework for the responsible and safe management of spent fuel and radioactive waste also clarifies this notion of waste, making the Member State responsible for the classification of a substance as either radioactive waste or radioactive material: a radioactive waste is “a radioactive substance in gaseous, liquid or solid form for which no subsequent utilisation is planned or envisaged by the Member State, or by any legal or natural person whose decision is accepted by the Member State, and which is considered to be radioactive waste by a competent regulatory authority within the legislative and regulatory framework of the Member State”. Therefore, classification of a substance as a radioactive material may be the result of the decision by the State (this is for example the generic case of spent fuel pursuant to Article L. 542-1-2 of the Environment Code) or a decision by its owner. In this latter case, the regulatory authority may oppose this classification and request classification as radioactive waste.

A radioactive substance is classified as **ultimate radioactive waste** when this waste “can no longer be processed in current technical and economic conditions, in particular by extraction of its reusable part or by mitigation of its polluting or hazardous nature”.

In France, when a substance contains radionuclides, the justification for radiation protection checks is not necessarily established as of an activity or concentration threshold per radionuclide. The justification for such a check is conservatively considered to be established when substances come from a nuclear[3] activity and are contaminated, activated, or liable to be so.

Nuclear activities (article L. 1333-1 of the Public Health Code) are “activities comprising a risk of human exposure to ionising radiation (…) emanating either from an artificial source (…) or from a natural source, when the natural radionuclides are processed or have been processed for their radioactive, fissile or fertile properties (…)”. Within the context of transposition of Council directive 2013/59/Euratom of 5th December 2013 setting basic standards for health protection against the dangers resulting from exposure to ionising radiation, this notion of nuclear activity was extended by the ordinance of 10th February 2016, containing various nuclear-related provisions, to

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[2] For example, when a nuclear fuel which was used in reactor operation is finally removed from the core of the reactor (“**spent fuel**”), it still contains substances that can be used. The spent fuel is processed in France for extraction of the reusable materials, that is plutonium and uranium, hence classification as radioactive material.

[3] Except for marginal nuclear activities which are exempt from licensing or notification, in which only “very small quantities” of radionuclides are used and for which a defined activity level is not exceeded (Article R. 1333-18 of the Public Health Code).

all natural sources of radioactivity, provided that they warrant the implementation of radiation protection checks.[4]

For nuclear activities covered by the BNI regime, secret BNIs (SBNI, ie. BNIs for the defence sector), installations classified on environmental protection grounds (ICPE) and for those authorised, registered or declared under the Public Health Code, all waste that is contaminated, activated or liable to be so, is conservatively managed as if it were radioactive. It must therefore undergo specific, reinforced management, which more particularly includes disposal of the ultimate waste in a centre dedicated[5] to radioactive waste.

Unlike the policy adopted by several other European countries regarding the management of very low-level waste, French regulations make no provision for a clearance level exempting very low-level waste from this obligation[6] but they do make a distinction between radioactive waste and "conventional" waste produced by a nuclear activity based on a geographical zoning of the places in which it is produced, determined by an operating analysis of the installation rather than a radioactivity measurement. Waivers to these provisions may nonetheless be granted if alternative management modes are considered to be justified, that is if they present more benefits than drawbacks without creating any significant health impact.

The choice made by France in the 1990s to adopt a radioactive waste management policy without using clearance levels, followed a series of incidents which revealed that it was possible for potentially contaminated waste to find its way into conventional routes[7]. The French management mode, primarily based on the origin of the waste, guarantees that all potentially radioactive waste from the BNIs is managed in dedicated routes and traced from waste production up to disposal. It is particularly easy to use in the field[8], which means that it has been taken on board by the entire chain, thus guaranteeing its robustness.

The work done on the recycling of certain very low-level materials, in compliance with the national regulatory framework, is presented in Chapter 3.5.5 of this Plan.

For the other activities, the need or otherwise for radiation protection checks is assessed according to the limited exposure criterion: the sum of effective doses due to these activities received by any

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[4] The ordinance defines nuclear activities as being "activities comprising a risk of exposure of individuals to ionising radiation resulting from the use either of an artificial source, whether a substance or device, or a natural source, whether naturally occurring radioactive substances or materials containing natural radionuclides". The entry into force of this definition is however deferred (no later than 1st July 2017)

[5] With the exception of waste managed by radioactive decay, pursuant to ASN resolution 2008-DC-0095 of 29th January 2008.

[6] Pursuant to Directive 2013/59/Euratom of 5th December 2013 setting basic standards for health protection against the dangers resulting from exposure to ionising radiation, which authorises an approach including the clearance concept - which corresponds to removing a material from the regulated domain, certain countries utilise clearance levels, expressed as a specific activity (Bq/g), which are either universal (regardless of the material, its origin and its purpose) or dependent on the material, its origin and its purpose.

[7] A detailed explanation of this decision is given in the 2007-2009 edition of the PNGMDR.

[8] The absence of a clearance procedure at the exit from the area of possible production of nuclear waste, means that it is possible to reduce the dedicated metrological checks, the definition and implementation of which (metrological traceability, validation of measurement methods, determination of detection limits, etc.) are potentially time-consuming and costly.

exposed person must not exceed 1 mSv per year[9] and according to an acceptability study on the radiological impact associated with handling of the waste, which must demonstrate that radiation protection checks are not justified. In this case and in certain conditions, the waste may be no longer considered as radioactive and may be accepted in conventional disposal facilities. The waste concerned is more particularly waste with high natural levels of radioactivity, for which the management conditions are described in Chapter 3.3 of this report. Within the framework of the transposition of directive 2013/59, these management procedures will be reviewed if the activities using radionuclides of natural origin, for which exposure cannot be ignored from the radiation protection viewpoint, are now to be considered nuclear activities.

1.1.2 Origin of radioactive materials and waste

Radioactive substances can be natural or the consequence of human activities, although, in certain cases, the boundary between these two origins is not easily defined. For example, certain natural materials can be used by man in such a way that the natural radioactive elements are concentrated, even though their radioactive properties are not necessarily used.

There are many sources of naturally occurring radiation: ore and materials containing radionuclides naturally present in our environment (isotopes of uranium and of thorium, tritium, potassium 40, carbon 14, or daughter elements such as radium and radon), cosmic radiation and so on. Natural radionuclides are to be found in all compartments of the environment. Moreover, the concentration of radionuclides varies widely depending on the material and its origin: exposure to radionuclides of natural origin can vary by more than an order of magnitude in the various regions of the world (from an average of 2.4 mSv/year in France, to more than 50 mSv/year in some parts of India, Iran, or Brazil).

In addition to these natural sources, the handling of radioactive substances in human activities since the early 20th century has led to the production of radioactive materials and waste, which come primarily from five economic sectors:

- the nuclear power generating sector, primarily nuclear power plants generating electricity (NPP), plus the plants dedicated to the fabrication and processing of nuclear fuel (extraction and processing of uranium ore, chemical conversion of uranium concentrate, enrichment and fabrication of fuel, processing of spent fuel and recycling);
- the research sector, comprising research in the civil nuclear field (mainly CEA research activities), medical research, particle physics, agronomy, chemistry laboratories,
- the defence sector: mainly activities related to the nuclear deterrent force, including the nuclear propulsion of certain ships or submarines, as well as the corresponding research activities;
- industry unrelated to nuclear power generation, notably the extraction of rare earths, the manufacture of sealed sources, but also various applications such as weld inspections, the sterilisation of medical equipment, the sterilisation and conservation of food products,
- the medical sector, comprising therapeutic, diagnostic and research activities.

The sectors which have historically made the largest contribution to the production of radioactive waste in France are nuclear power generation and research, mainly in the civil nuclear field and, to

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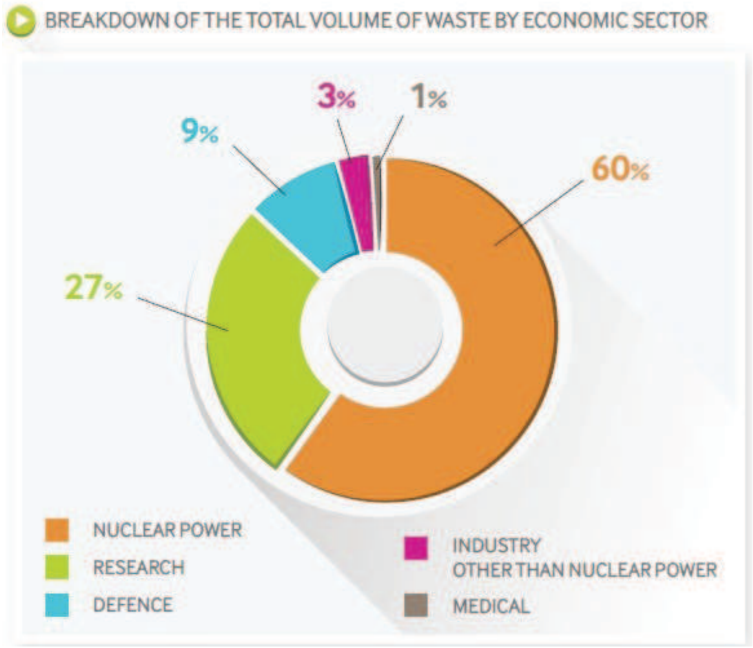
[9] Article R.1333-8 of the Public Health Code states that "the sum of the effective doses received by any person not in the categories mentioned in Article R. 1333-9, as a result of nuclear activities, shall not exceed 1 mSv/year."

a lesser extent, defence. The respective contributions of each of these sectors to the stocks of waste as at the end of 2013 (excluding "legacy" waste and waste "already produced" by the conversion plant in Malvési) is given in the following figure. With regard to the research sector, which accounts for 27% of the volume of waste, 95% of this volume comes from CEA and 5% from other research organisations (CNRS, universities, etc.).



(Source: Andra)

1.1.3 Usual classification of radioactive materials and waste

In accordance with the definitions specified in section 1.1.1, a distinction is made between radioactive materials and radioactive waste.

The management modes for radioactive substances considered to be radioactive materials are presented in part 2 of this document; the management modes for radioactive substances considered to be radioactive waste are presented in parts 3 and 4.

Radioactive materials are not covered by any particular classification. This in fact mainly concerns radioactive substances for which further use is planned or envisaged, owing to their radioactive, fissile, fusible or fertile properties, in other words mainly uranium (natural, enriched or depleted), fuels (in use or spent), uranium and plutonium separated by processing of spent fuels, and reusable materials from industries other than nuclear power generation (mainly materials containing thorium).

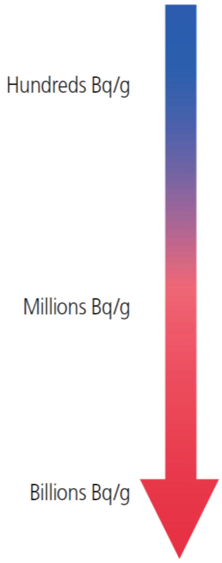
With regard to radioactive waste, the usual French classification is based mainly on two parameters for defining the appropriate management method: the activity level of the radioactive elements contained and their radioactive half-life. These two criteria can be linked to the harmfulness of these waste and the period for which they remain harmful. A particular distinction is made between waste primarily containing radionuclides with a half-life of less than 31 years (waste referred to as "short lived") and waste primarily containing radionuclides with a half-life of more than 31 years (waste said to be "long-lived").

This classification comprises the following main categories:

- **high-level waste (HLW)**, mainly consisting of vitrified waste packages from spent fuels after processing. These waste packages contain most of the radioactivity from all of the waste, whether fission products or minor actinides. The activity level of this waste is about several billion becquerels per gram (Bq/g) at the time it is produced and packaged;
- **intermediate level, long-lived waste (ILW-LL)**, mainly from spent fuels after processing and activities involved in the operation and maintenance of fuel processing plants. This comprises structural waste, hulls and end-pieces making up the nuclear fuel cladding, conditioned in cement-encapsulated or compacted waste packages, along with technological waste (used tools, equipment, etc.) or waste resulting from the treatment of effluents, such as bituminised sludges. The activity level of this waste is about one million to one billion Bq/g;
- **low level, long-lived waste (LLW-LL)**, mainly graphite waste and radium-bearing waste. Graphite waste comes primarily from the decommissioning of gas-cooled reactors (GCR). The graphite from these reactors contains long-lived radionuclides such as carbon 14 (half-life 5,700 years). Its radioactivity level is several hundred thousand Bq/g. Radium-bearing waste is mainly produced by the nuclear industry unrelated to power generation (such as the processing of ores containing rare earths) and has a level of between several tens and several thousands of Bq/g. This LLW-LL category also comprises other types of waste, such as certain legacy bitumen packages, uranium conversion treatment residues from the Areva plant in Malvési, and so on;
- **low level and intermediate level, short-lived waste (LLW/ILW-SL)**, mainly from the operation, maintenance and decommissioning of nuclear power plants, fuel cycle facilities, research centres and, to a far lesser extent, from medical research activities. The level of this waste is between a few hundred and a million Bq/g;

- **very low level waste (VLLW)**, mainly from the operation, maintenance and decommissioning of nuclear power plants, fuel cycle facilities and research centres. The activity level of this waste is generally less than 100 Bq/g;
- **very short-lived waste (VSL)**, mainly from the medical and research sectors. It is stored on the utilisation site to allow radioactive decay, before disposal through a conventional route, corresponding to its physical, chemical and biological characteristics.

In schematic terms, this classification enables each waste category to be associated with one or more management solutions, which will be described in more detail below. They are summarised in the following table.



	Very short lived waste containing radionuclides with a half-life of < 100 days	Short lived waste in which the radioactivity comes mainly from radionuclides with a half-life ≤ 31 years	Long-lived waste containing a significant quantity of radionuclides with a half-life > 31 years[10]
Very low level (VLL)	Waste management by radioactive decay	Recycling or dedicated surface disposal	
Low level (LL)		Surface disposal except for certain tritiated waste and certain sealed sources	Near-surface disposal Solution being examined under Article 4 of the 28th June 2006 Act
Intermediate level (IL)			Deep geological disposal Solution being examined under Article 3 of the 28th June 2006 Act
High level (HL)	Not applicable[11]		

Radioactive waste classification principles

Two important aspects must be underlined with regard to the radioactive waste classification:

- There is no single classification criterion for determining the category of a waste. The radioactivity of the various radionuclides present in the waste must first be studied in order to classify it in a particular category. However, despite the absence of a single criterion, the waste in each category are generally within a specific radioactivity range as shown above;
- waste can fall into a particular category, but may not be accepted by the corresponding management route because of other properties (for example its chemical composition or physical properties).

1.1.4 Inventory of radioactive materials and waste

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[10] Or a concentration of elements with a half-life shorter than 31 years, higher than the acceptance criteria for a surface repository

[11] There is no high level, very short-lived waste category.

In compliance with the legislative and regulatory provisions detailed in Chapter 1.3, a National Inventory of radioactive materials and waste is produced, updated and published every three years by the French National Radioactive Waste Management Agency (Andra) on the basis of declarations submitted by the radioactive waste producers and those in possession of radioactive materials. It comprises the following documents:

- the “Essentials of the National Inventory”, comprising summary and complete data on stocks and forecasts,
- the “Summary report”,
- the “Descriptive catalogue of families” of radioactive waste,
- the “Geographical inventory”, compiling all the declarations submitted by the producers and those in possession of radioactive materials and waste,
- a document intended for the general public called “A Review of the National Inventory”.

The 2015 edition of the National Inventory details the quantities of radioactive waste stored or disposed of as at the end of 2013, their location and their breakdown per category and economic sector. This edition presents the waste production forecasts for the end of 2020, the end of 2030 as well as at the end of the lifetime of the existing or authorised facilities, according to the scenarios defined by the industrial operators of these facilities. The National Inventory also presents the forecast inventories produced according to two intentionally contrasting energy scenarios. This Inventory also identifies the quantities and forecasts for radioactive materials and includes information about legacy disposals on the production sites, polluted sites and existing or planned solutions in France for radioactive waste management.

A summary of the data contained in this National Inventory is presented in the following sections.

R1 – On the basis of annual declarations by the producers, Andra presents a yearly update of the quantities of waste disposed of or stored, at a meeting of the PNGMDR working group.

Radioactive waste

The following table summarises the quantities of radioactive waste for each waste category as at the end of 2013 and the forecasts as at the end of 2020, end of 2030 and at the end of the lifetime of the facilities. The forecasts used for these reports are based on an estimate of the waste produced[12] as at the dates in question by the facilities in operation or for which creation has been authorised as at 31st December 2013, and scheduled for acceptance by the Andra disposal facilities. They do not take account of the waste “already produced” by the Malvési conversion plant, for which the long-term management route is currently being studied (see Chapter 4.3.5), nor waste which has been handled by “legacy”[13] management modes such as:

- uranium ore processing residues, disposed of on certain former mining sites. The National Inventory identifies 20 surface sites on which these residues are permanently stored in-situ;
- waste disposed of on “in-situ legacy sites” which in the past entailed disposal near to the nuclear facilities or plants. This usually takes the form of embankments or backfill;
- waste immersed by France in the North-East Atlantic in 1967 and 1969 and in the territorial waters of French Polynesia.

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[12] A distinction must be made between “waste produced” and “waste disposed of”. Waste can be produced but not yet have been placed in a dedicated repository.

[13] For more details on these sites, see the 2015 edition of the National Inventory.

The quantities of radioactive waste are given in equivalent packaged m^3 (volume of waste once contained in a primary package). In this summary table, the figures are rounded off to two significant digits, with the possible exception of the totals.

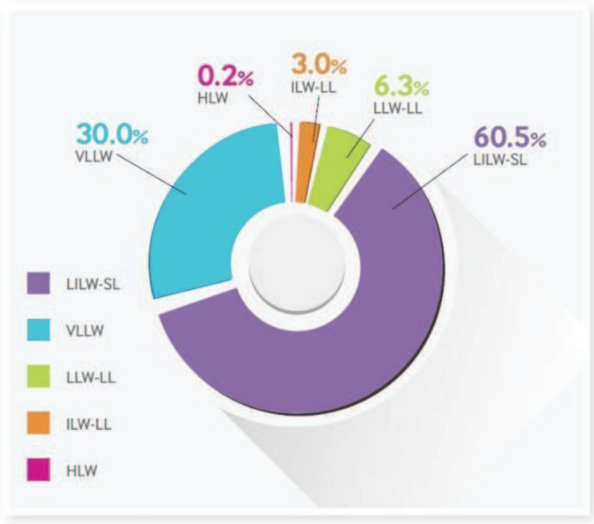
FORECAST OF RADIOACTIVE WASTE VOLUMES (m^3) AT THE END OF 2020 AND 2030 AND FINAL FORECASTS ACCORDING TO INDUSTRY SCENARIOS:

CATEGORY	QUANTITIES AT THE END OF 2013	FORECASTS FOR THE END OF 2020	FORECASTS FOR THE END OF 2030	FINAL FORECASTS
HLW	3,200	4,100	5,500	10,000
ILW-LL	44,000	48,000	53,000	72,000
LLW-LL	91,000	92,000	120,000	180,000
LILW-SL	880,000	1,000,000	1,200,000	1,900,000
VLLW	440,000	650,000	1,100,000	2,200,000
TOTAL	~1,460,000	~1,800,000	~2,500,000	~4,300,000

(Source: Andra)

The breakdown by category of the volume of radioactive waste as at the end of 2013 (excluding “legacy” waste and waste “already produced” by the Malvési conversion plant) is given below:

BREAKDOWN OF WASTE CATEGORIES BY VOLUME



(Source: Andra)

Furthermore, as at the end of 2013, 3,800 m^3 of radioactive waste were still without a management route (existing or planned), either because it is insufficiently characterised, or because its chemical or physical form prevents it from being directly associated with a management route. It is allocated to the “waste with no disposal route” category in the National Inventory. The studies under way to identify solutions for this waste are described in Chapter 4.3.1.

Although it only represents 0.2% of the total volume, as shown in the above figure, high level waste nonetheless accounts for 98% of the radioactivity[14]:

Activity in TBq	α	β/γ short-lived	β/γ long-lived	Total activity
HLW	3 500 000	212 000 000	347 000	~ 220 000 000
ILW-LL	44 000	4 300 000	1 100 000	~ 5 500 000
LLW-LL	720	16 000	2 800	~ 19 000
LL/ILW-SL	910	27 000	8 300	~ 36 000
VLLW	3	4	1	~ 8

With regard to the forecasts, it should be noted that the declaration of forecasts of waste production at the end of operation of the facilities is now required, unlike in the previous editions. These forecasts were drawn up by the producers according to industrial scenarios based on their strategic vision as at the end of 2013.

These end of operating lifetime forecasts confirm that the VLL waste repository should become saturated some time between 2025 and 2030, depending on the capacity increases which could be granted for this repository. They also highlight the need to optimise the management of LLW/ILW-SL category waste, for example by reducing their production at source, through improved characterisation and better sorting, or by improving their packaging: current forecasts reveal that if no optimisation efforts are made and assuming constant production rates, the volume of LLW/ILW-SL waste will reach the total dedicated disposal capacity between 2040 and 2050.

Radioactive materials

The following table presents the quantities of radioactive materials notified as at the end of 2013, plus the forecasts for the end of 2020 and end of 2030, expressed in tonnes of heavy metal (tHM), except for spent fuels from the National Defence sector.

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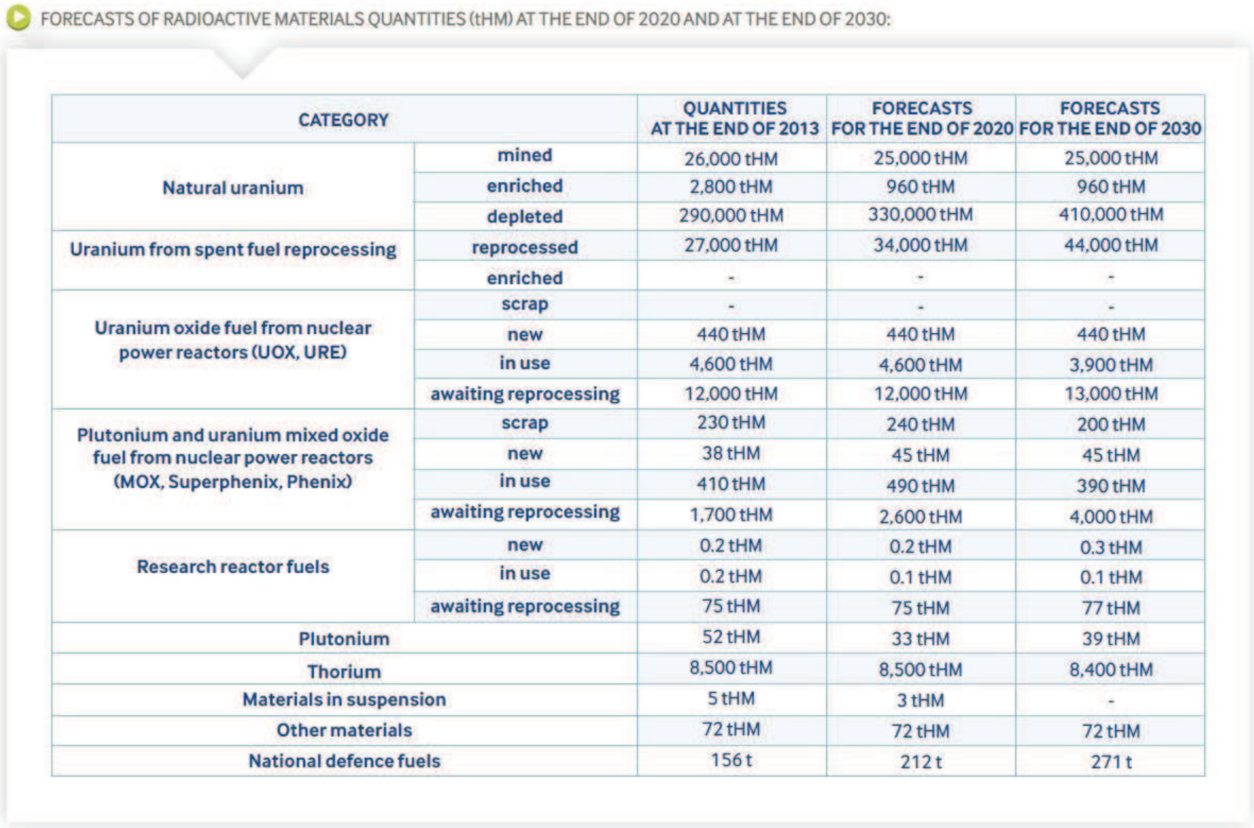
[14] The convention for the calculation of radiological activity was modified with respect to that of the 2012 edition of the National Inventory: the daughter radionuclides in secular equilibrium are now included in the calculations, which allows a direct comparison with the activities measured.


FORECASTS OF RADIOACTIVE MATERIALS QUANTITIES (tHM) AT THE END OF 2020 AND AT THE END OF 2030:

CATEGORY		QUANTITIES AT THE END OF 2013	FORECASTS FOR THE END OF 2020	FORECASTS FOR THE END OF 2030
Natural uranium	mined	26,000 tHM	25,000 tHM	25,000 tHM
	enriched	2,800 tHM	960 tHM	960 tHM
	depleted	290,000 tHM	330,000 tHM	410,000 tHM
Uranium from spent fuel reprocessing	reprocessed	27,000 tHM	34,000 tHM	44,000 tHM
	enriched	-	-	-
Uranium oxide fuel from nuclear power reactors (UOX, URE)	scrap	-	-	-
	new	440 tHM	440 tHM	440 tHM
	in use	4,600 tHM	4,600 tHM	3,900 tHM
	awaiting reprocessing	12,000 tHM	12,000 tHM	13,000 tHM
Plutonium and uranium mixed oxide fuel from nuclear power reactors (MOX, Superphenix, Phenix)	scrap	230 tHM	240 tHM	200 tHM
	new	38 tHM	45 tHM	45 tHM
	in use	410 tHM	490 tHM	390 tHM
	awaiting reprocessing	1,700 tHM	2,600 tHM	4,000 tHM
Research reactor fuels	new	0.2 tHM	0.2 tHM	0.3 tHM
	in use	0.2 tHM	0.1 tHM	0.1 tHM
	awaiting reprocessing	75 tHM	75 tHM	77 tHM
Plutonium		52 tHM	33 tHM	39 tHM
Thorium		8,500 tHM	8,500 tHM	8,400 tHM
Materials in suspension		5 tHM	3 tHM	-
Other materials		72 tHM	72 tHM	72 tHM
National defence fuels		156 t	212 t	271 t

(Source: Andra)

Inventory forecasts

The National Inventory also gives forecasts of the waste and materials that would be produced by all the facilities until the end of their life. These quantities are presented according to two intentionally contrasting nuclear power generating policies, which in no way prejudge any decision with respect to French energy policy. The activity of the economic sectors other than nuclear power generation is assumed to be identical in both scenarios.

In both cases, the inventory only concerns the waste produced by facilities which have a creation authorisation decree as at the end of 2013, even though the "continuation" scenario implies the commissioning of new facilities.

Scenario 1: continuation of nuclear power generation

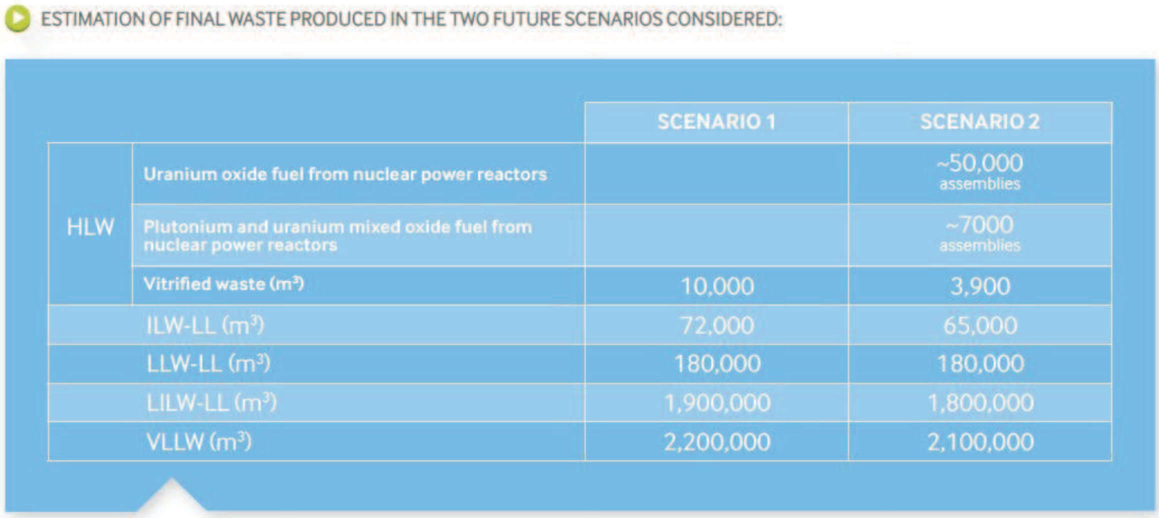
This scenario is based on two factors: the continued production of electricity from nuclear power, while maintaining the current strategy of spent fuel processing. It considers an average operating lifetime of 50 years for all the reactors, while guaranteeing a total maximum nuclear electricity production capacity of 63.2 GWe. It assumes that all the fuels consumed by the reactors authorised as at the end of 2013 is processed in existing or future plants, for separation of radioactive materials (uranium, plutonium) from ultimate waste. No spent fuel is then directly disposed of and all the plutonium extracted from the spent fuels is recycled in the existing or future power plants, in the form of mixed uranium and plutonium oxide fuels.

Given the number and age of the reactors today authorised to use this type of fuel, the NPPs in operation will be able to reuse the separated plutonium until about 2029. Beyond that date, the rate of processing of spent fuel and thus the production of plutonium will depend directly on the rate of deployment of the new reactors consuming it. These spent fuels (UOx, MOx) produced by the existing NPPs, up to the end of their operating lifetime, would represent about 30,000 tHM to be recycled.

Scenario 2: non-renewal of the NPP fleet

This scenario implies non-renewal of the existing fleet and the cessation of spent fuel processing before shutdown of the reactors, to avoid producing separated plutonium. It takes account of a reactor operating lifetime of 40 years. Plutonium recycling is limited to the fabrication of the MOx fuel needed to operate the reactors today authorised to use this type of fuel. The shutdown dates for these reactors indicate that the separation of plutonium by processing of the spent fuels will cease to be necessary as of 2019. In this scenario, about 28,000 tHM from UOx and MOx spent fuels, will become waste and need to be disposed of (in the same conditions as HL waste).

The following table gives an estimate of the waste produced by both envisaged scenarios.



ESTIMATION OF FINAL WASTE PRODUCED IN THE TWO FUTURE SCENARIOS CONSIDERED:

		SCENARIO 1	SCENARIO 2
HLW	Uranium oxide fuel from nuclear power reactors		~50,000 assemblies
	Plutonium and uranium mixed oxide fuel from nuclear power reactors		~7000 assemblies
	Vitrified waste (m^3)	10,000	3,900
ILW-LL (m^3)		72,000	65,000
LLW-LL (m^3)		180,000	180,000
LILW-LL (m^3)		1,900,000	1,800,000
VLLW (m^3)		2,200,000	2,100,000

(Source: Andra)

Spent fuels are not today considered to be radioactive waste and are not therefore packaged for acceptance in a repository. The average volume of a fuel assembly being about 0.2 m^3, these unpackaged assemblies represent a total volume of about 12,000 m^3. Andra studied the feasibility of spent fuel disposal in 2012 and the disposal container concepts used for this demonstration led to a volume of about 89,000 m^3 of disposal packages (about 8 times more than the unpackaged volume). The 2013-2015 PNGMDR asked for an update of this study, which should be communicated by Andra in 2016.

1.2 *The principles to be considered when defining the radioactive waste management routes*

The usual classification of radioactive waste, taking account of the activity level and half-life of the radioactive substances, offers a simple means of routing radioactive waste and identifying the respective routes. However, it does not take account of certain complicating factors which lead to a management route being chosen that is different from the category into which the waste falls. Other criteria, such as stability, the presence of toxic chemical substances, or even the potential attractiveness (for used sealed sources especially) of the waste, must be taken into account.

In addition, the definition of a management mode must take account of the principles and guidelines defined in Chapter I of title IV of book V of the Environment Code, more specifically the need to reduce the volume and harmfulness of ultimate radioactive waste. The optimisation of waste processing operations, the optimisation of the doses received by individuals and the reduction of the impact on the populations must also be sought.

Radioactive waste management falls within the general framework defined in Chapters I and II of title IV, book V of the Environment Code. Radioactive waste must therefore be managed, as far as is reasonably feasible, in order to achieve the following objectives:

- as a priority, prevent and reduce the production and harmfulness of radioactive waste, in particular by modifying the design and operating procedures of the nuclear facilities. The processes implemented must therefore be the subject of optimisation studies, during all the phases in the lifetime of the facilities (design, operation and decommissioning) with the aim of mitigating their impacts on the environment;
- for the radioactive waste produced, implement a hierarchy of management modes, with the following order of preference: sorting prior to reutilisation, recycling, reuse and, finally, disposal of ultimate waste. Prior to disposal, appropriate processing and packaging should enable a reusable part to be extracted and reduce their quantity and harmfulness. Reserving disposal only for ultimate waste helps limit the quantities of waste intended for these facilities, which have limited capacity, the use of which must be optimised;
- a producer of radioactive waste is responsible for its management or for ensuring that it is managed. In this respect, it must in particular define a management route for all types of radioactive waste it produces.

1.2.1 Prevention, reduction in the production and harmfulness of waste and integration of the management routes as of the design stage of the facilities

The quantity and harmfulness of the waste to be produced by the operation and then the decommissioning of nuclear facilities must be minimised as far as is possible. In this respect, design and organisational steps must be taken and implemented. Such steps include in particular:

- study of the mechanisms involved in the dissemination of radioactive substances or the activation of structures then optimisation of the resulting waste zoning in the design of the facilities, in order to limit the extent of the zones in which the waste produced is contaminated, activated, or liable to be so. This zoning must be regularly updated, in particular when decommissioning operations begin, in order to minimise the production of radioactive waste;
- the implementation of a radiological cleanness approach in the facilities;
- the implementation of organisational measures such as to minimise the equipment (devices, tools, clothing, vinyl sheets, etc.) used in the zones, in which they could become contaminated or activated;
- careful selection of the materials used in the facilities, ensuring that their properties, chemical in particular, are known, are appropriate for the phenomena to which they are liable to be subjected and are compatible with the existing or future radioactive waste management routes. This helps ensure, on the one hand, that the management routes will be available as and when required and, on the other, that the volume and harmfulness of the waste produced is limited to the extent possible, if necessary after processing. In this respect, the selection of materials aims to:
    - limit activation, including of any impurities present in the materials, especially when the activation products are long-lived;
    - limit the presence of toxic chemicals, fibrous insulating materials, complexing species or pyrophoric elements in the waste;
    - facilitate the decontamination of surfaces;
- the selection of the equipment used in the facilities, such as to minimise the quantity of waste produced by maintenance operations.

In its opinion of 20th July 2016[15] on the draft 2016-2018 PNGMDR, the environmental authority recommended that the notion of harmfulness as applied to radioactive materials and waste be defined more precisely. The environmental authority also recommends that the eco-toxicity of the substances and their impact on human health be described, as related to the evolution of their activity and their composition over time.

R2 – Before 31st December 2017, IRSN will submit a report on the possible methodology and criteria for assessing the harmfulness of radioactive materials and waste. This report includes considerations on the evolution of the characteristics of radioactive materials and waste over the short, medium and long-term, their eco-toxicity and the impact associated with the management modes envisaged in the PNGMDR.

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[15] This opinion (n° Ae: 2016-036) is available on the website of the General Council for the Environment and Sustainable Development: http://www.cgedd.developpement-durable.gouv.fr.

1.2.2 Reutilisation routes

The implementation of reutilisation routes must be encouraged in order to comply with the hierarchy of management modes but, owing to the particularities of radioactive substances, it is very closely monitored.

The recycling of radioactive waste from nuclear activities is thus limited on the one hand by the geographical approach based on the principle of waste zoning and the absence of any clearance level (see section 1.1.1) and, on the other, by restrictions on the reutilisation possibilities set out in Article R. 1333-3 of the Public Health Code. This Article prohibits the use of materials and waste from a nuclear activity in the manufacture of consumer goods and construction materials, when they are, or are liable to be, contaminated by radionuclides, including through activation, as a result of this activity. A waiver to this ban is however possible, in the conditions set out in the Order of 5th May 2009 stipulating the composition of the file and the consumer information procedures required by Article R. 1333-5 of the Public Health Code.

The reutilisation routes adopted in France in recent years meant that recycled substances could only be used within nuclear facilities. Under the terms of the 2013-2015 PNGMDR, and in addition to the studies submitted by Areva, EDF, CEA and Andra respectively, the conditions for the reutilisation of very low level materials were also examined by a pluralistic working group. The results of this work as a whole were published on the websites of ASN[16] and the Ministry for Energy[17] and are presented in Chapter 3.5.

1.2.3 Definition of a management route for ultimate radioactive waste

Definitions

A **management route** for radioactive waste refers to all the operations performed on the radioactive waste which, from production to disposal, contribute to ensuring that it is made safe, once and for all. It is adapted to certain types of radioactive waste.

The successive operations carried out in a radioactive waste management route comprise:
- collection, characterisation and sorting at source;
- processing and packaging;
- storage;
- disposal.

These operations are supplemented by transportation either on a given site or between two separate sites. It should also be borne in mind that these operations can be repeated, for example if several packaging operations carried out in different facilities are required.

Each step along a management route must be carried out safely and each licensee involved in it is responsible for the safety of the facilities it operates and the activities it performs. However, it is essential to take account of the fact that all the operations in a given management route are closely interconnected: each of these operations must therefore be planned and performed so that it is compatible with the following ones and in such a way as to ensure overall optimisation.

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[16] http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015.

[17] http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

The **collection at source** of radioactive waste aims to ensure that all the radioactive waste produced is dealt with exhaustively. In this respect, the waste management policy in force requires that the waste producers operating under the BNI or ICPE systems or carrying out a nuclear activity covered by Article L. 1333-1 of the Public Health Code, must produce a waste management study, which will in particular present and substantiate the procedures for defining and managing waste zoning, identifying the zones in which the waste produced is contaminated, activated, or liable to be so.

Sorting at source of radioactive waste consists in separating the waste according to its physico-chemical nature (solids, liquids, solvents, etc.), its radiological characteristics and the specific risks other than radiological that it can present (risk of infection, etc.). This sorting must be able to prevent any mixing between waste categories (in other words between waste which are not intended for the same route) or between incompatible substances.

The **characterisation** of waste consists in measuring and identifying the radiological, chemical, biological and physical characteristics of the waste so that its compatibility with the planned subsequent management steps can be verified.

The **processing** of radioactive waste consists in transforming the initial waste to give it characteristics that are more appropriate (more specifically in terms of volume or physico-chemical characteristics) for its subsequent management. Processing can also be used to extract a possible reusable part. For example, we could mention: incineration, evaporation, compacting and melting.

Packaging is all the operations carried out to produce a package[18] of radioactive waste. These operations may in particular consist in placing in a container, immobilisation, physico-chemical processing or encapsulation of radioactive waste. The containers in which the radioactive waste is placed are generally made of concrete, non-alloy steel (carbon steel), or alloy steel (stainless steel) and, in any case, appropriate to the installations for which they are intended and, with regard to radioactivity, appropriate to the physico-chemical properties and the lifetime of the waste they contain.

Storage consists in temporarily placing radioactive waste in a specially designed surface or near-surface facility, with the intention of subsequently removing it.

Disposal consists in placing the radioactive waste in a specially designed facility, potentially definitively, with no intention of subsequently removing it.

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[18] System comprising solid radioactive waste which has characteristics and physical, chemical, mechanical and radiological properties enabling it to be managed in compliance with the safety requirements of the facility in which it is being handled and which are also compatible with the conditions set out for its subsequent management, including handling, transportation, storage and disposal, if necessary after modifications, over-packing or use of an appropriate packaging.

Parameters to be considered when defining management routes appropriate to the nature and diversity of waste

Several parameters must be considered when defining a waste management mode. The main parameters are as follows:

Management principles

Radioactive waste management modes must be defined in compliance with the principles set out in the Environment Code (Chapter I and II of title IV of its book V) and in directive 2011/70/Euratom of 19th July 2011:

- protection of the health of individuals, safety and the environment;
- prevention and mitigation of the burden to be borne by future generations;
- reduction in the quantity and harmfulness of radioactive waste, more specifically through appropriate processing and packaging methods;
- organising waste transport and limiting both distances and volumes;
- ensuring public information of the effects of the waste production and management operations on the environment and on public health, subject to the confidentiality rules laid down by law, as well as measures designed to prevent or compensate for the prejudicial effects.

This definition of a management route must be carried out in a graded approach commensurate with the risk and the impacts, using an assessment of the costs (financial, human, environmental, etc.) versus the expected benefits of implementing a management solution.

The protection of individual health includes both employees and the general public. It is based more specifically on application of the principles of protection against ionising radiation contained in the Public Health Code: justification of activities (technical, economic and ethical), mitigation of the consequences (doses) and optimisation of protection (doses). The effectiveness of the optimisation approach is based on the widespread dissemination of the radiological risk culture.

Health and environmental impacts of the radioactive waste produced

In compliance with the principles mentioned in the previous point, the management route selected or envisaged must be appropriate to the potential hazards for the interests mentioned in book V of the Environment Code (safety, individual and public health or the protection of nature and the environment).

The classification of radioactive waste presented in section 1.1.3, based on the activity level and the half-life of the radionuclides contained in the waste, gives an idea of the harmfulness of the radioactive waste and of their decay over time. This gives a simple basis for routing the various waste categories (VSLW, VLLW, LLW/ILW-SL, LLW-LL and HLW and ILW-LL) and identifying the available routes, for which the management solutions must be appropriate to the hazards presented by each of the categories. The classification does not take account of certain complicating factors. For example, nuclear industry operating waste, even if it generally contains a vast majority of short-lived radionuclides, also often contains traces of long-lived radionuclides which must be taken into account in the safety analysis of a repository. Similarly, the differentiation between low level and higher level waste, based on the immediate radiological impact in the event of non-specific utilisation, is a simplification with regard to long-term management routes for which many other parameters have to be taken into account, such as the toxicity and chemical reactivity. Moreover, waste can also fall into a particular category, but may not be accepted by the corresponding management route because of other properties (stability, presence of certain chemical elements). These additional criteria must then be taken into account when defining an appropriate management route.

For certain legacy waste disposal situations, developed in section 3.1.3, the assessment (in current technical and economic conditions) of the nature, volume and health and environmental impacts of the radioactive waste present on a site, as compared with the costs, risks and health and environmental impacts to be expected from recovery and removal of the waste to existing disposal facilities, may lead the licensees to prefer to continue with in-situ management.

Management of inter-dependency and compliance with criteria for acceptance in the facilities

The criteria for acceptance of radioactive waste in the various waste management facilities are precise, which more specifically requires waste characterisation and packaging operations. Moreover, these criteria limit or rule out the presence of certain materials in the waste packages.

With regard to the characterisation operations, a clear understanding of the radiological and physical-chemical content of the waste package helps optimise its packaging and its management route and contributes to the safety of subsequent management operations.

With regard to packaging operations, the purpose of manufacturing a waste package is generally to contain the waste in a stable, solid monolithic form[19]. Processing prior to packaging is also sometimes necessary to ensure compatibility, especially physico-chemical compatibility, between the waste and the matrix, or immobilisation system, chosen for the composition of the package. Glass and cement are the main matrices used industrially and have been employed for many years now. The studies to be carried out in the coming years will aim to improve the performance of these processes, either by boosting their production capacity, or by expanding their scope of application to include different waste, or to develop new matrices with the aim of optimising the containment properties of certain packages. The packaging operations can imply radioactive waste transformations that would be hard to reverse. Before they are performed, their compatibility with the subsequent steps in the management route must therefore be verified.

Optimisation of a management route also means following a safety approach so that the repository can perform its containment function until the radioactivity of the radionuclides contained in the waste has sufficiently diminished. The radiological impact of the management solution adopted must be as low as reasonably achievable (ALARA principle).

The need for a long-term balance between requirements and resources

The capacity and availability of the long-term management solutions in relation to the overall requirements, must be monitored and anticipated in order to avoid waste production creating needs that exceed the available and authorised or planned capacity.

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[19] If the package cannot on its own guarantee sufficient intrinsic safety, it is emplaced in a structure in which the voids are filled with concrete.

It would therefore seem to be essential that the waste producers define a medium and long-term management strategy for their waste, so that either individually or together with other producers, they can set up solutions for each step in the waste management process and plan ahead to ensure availability of the means (storage, processing and packaging facilities, transport packagings, etc.) necessary for optimised management. These strategies are regularly examined by the safety regulators.

With regard to the waste which could result from the operation of future nuclear facilities or new types of nuclear facilities, such as the waste which would be produced by the possible operation of a fleet of fast neutron reactors or nuclear fusion reactors, its management will have to be examined with respect to the existing solutions, in order to demonstrate their compatibility or define the necessary changes to the existing solutions, or the creation of new ones (compatibility with the disposal acceptance specifications, consequences for the repository footprint, etc.).

Use of the best available techniques, impact mitigation, optimisation between discharges and waste

The Environment Code requires that the licensees apply the best available techniques and aim to minimise discharges to the extent possible, in acceptable technical and economic conditions and in complete safety. These provisions are in-line with the objective defined by the Sintra ministerial declaration of 1998 (Ospar Convention) which sets a 2020 deadline for achieving environmental levels close to the ambient levels for substances naturally present and close to zero for artificial substances, by means of gradual and substantial reductions in radioactive discharges, emissions or losses, taking account of technical feasibility and the impact on man and the ambient environment.

Discharges from facilities are limited by recovering radionuclides or other chemical substances from the effluents and through concentration and containment of waste. In certain cases, the impact of a discharge is lower than the impacts it would have if managed as waste. This break-even point is determined on a case by case basis, through a multi-criterion optimisation process which, among other things, takes account of lifecycle analyses of products and services, nuclear safety and radiation protection and which, for constant production levels, is constantly being lowered as technology progresses. A requirement linked to the optimisation process is imposed by the current regulations.

Furthermore, the waste assessments (periodically updated) produced by the licensees of nuclear facilities must explain the choices made between waste processing and discharge operations (decontamination of solid waste producing liquid effluents, processing of liquid effluents producing solid waste, etc.) and their containment methods, making use of the best available techniques. The primary goals of these processing operations is to reduce the quantity and harmfulness of the waste, and to implement an optimised management method. A description of liquid and gaseous effluent processing and the impact of this processing on the production of waste is presented, explaining the relationship between the quantities and qualities of the waste produced and the quantities and qualities of the liquid and gaseous effluents discharged. This study must reflect a comprehensive examination of the question of effluent and waste management.

The impact of a BNI is considered by the BNI system, which covers the risks of accidents, chronic releases, waste production and other detrimental effects. The same applies for a facility subject to the system of installations classified on environmental protection grounds (ICPE). An impact assessment in particular is systematically required for any activity leading to discharges into the environment. This analysis should guarantee that discharges from nuclear facilities do not compromise the interests protected by Article L.593-1 of the Environment Code. In order to mitigate the environmental impact, the licensees are systematically required to propose and implement techniques to reduce discharges linked to these activities to the extent made possible by the available techniques and in economically acceptable conditions. Discharges are the subject of prescriptions set by the ASN resolution for BNIs, by ministerial order for secret BNIs or by order of the prefect for ICPEs. These prescriptions strictly limit discharges for a certain number of substances and precisely regulate the means of treatment, purification and monitoring for effluents resulting from nuclear and industrial activities. The authorised discharges from nuclear facilities comply with limits such that the resulting exposure remains low with respect to natural exposure levels for the populations and the environment.

At the national or regional level, some topics are also the subject of specialised planning, for example through water development and management plans for water intake and liquid effluent discharges, or through the PNGMDR for radioactive waste. In this respect, the present Plan concerns waste and the management of radioactive materials, but does not cover effluent discharges.

Discharges and waste - position expressed by ASN and the DGEC

ASN and the Ministry in charge of the environment and energy underline the fact that there are indeed links between waste production and discharges and that the legal systems regulating nuclear activities are more specifically designed to enable the impact of these activities to be addressed in an integrated manner.

Basic nuclear installations and ICPEs are only authorised after a public inquiry more particularly concerning an impact assessment which includes both discharges and waste. The discharges themselves are regulated by requirements set by the Ministers or the Prefect, depending on the facility, after examination by the Departmental Council for the Environment and Technological Risks (CODERST) and, for a BNI and secret BNI, by the local information committee.

ASN's annual report on the state of nuclear safety and radiation protection presents annual data on the production of waste and effluent discharges. For each BNI, the discharge levels must also appear in the annual public information reports drawn up by the licensee, pursuant to Article L.125-15 of the Environment Code, made public and presented to the local information committees; these reports are available on the websites of the BNI licensees. Information about discharges must also be released to whomsoever requests it, pursuant to Article L. 125-10 of the Environment Code. For secret BNIs, an annual report on the nuclear safety of the site, the risks of radiological origin and the discharges produced by the installation, along with the steps taken to mitigate the impacts, is presented to the local information committees in accordance with the provisions of Article R. 1333-39 of the Defence Code, in accordance with national defence requirements.

In addition to the integrated systems for monitoring the impact of installations and activities, there are also specialised planning arrangements, for example with regard to waste management with the PNGMDR. To be correctly readable, the documents giving the results of this planning must not be taken out of their context. Thus the presentation of discharge management and levels is not covered by the provisions of Article L. 542-1-2 of the Environment Code, which sets the content of the PNGMDR and it would thus be liable to impair the legibility of the plan. In addition, the provisions of Article L. 542-1-1 of the Environment Code explicitly exclude licensed discharges from the scope of management of radioactive materials and waste.

Discharges and waste – position expressed by ACRO, supported by FNE, ANCCLI, Robin des Bois and Greenpeace

During the discussions held when drafting the 2016-2018 PNGMDR, ACRO reiterated its viewpoint, already expressed on the occasion of the 2013-2015 edition, concerning the inclusion of effluent discharges in this document. This viewpoint was also supported by FNE, ANCCLI, Robin des Bois and Greenpeace in the previous edition of the Plan.

"Certainly the regulatory frameworks for waste and for discharges are different, but the two aspects are inseparable, because radioactive discharges can frequently be the result of the decision to deal with radioactive waste on the basis of a "clearance level". In simpler terms the two problems are interrelated.

There are in fact technical retention solutions for virtually all radionuclides (starting with iodine 129, carbon 14 but also tritium, krypton 85 and so on) but, for technical and economic reasons, these technologies are not used. No doubt the most striking example is that of iodine 129, which is virtually entirely discharged at sea, even though retention systems, developed by France, exist and have been implemented in Japan on certain facilities as of the 1970s. Similarly, ACRO considers that carbon 14 is entirely discharged as effluent in our country, but is collected by chemical precipitation in other countries and thus managed as waste.

Although the addition of artificial radionuclides into consumer goods and foodstuffs is prohibited, it is authorised for discharge into the environment. The situation is paradoxical to say the least. If industry was to change its radioactive effluents management strategy, either voluntarily or if obliged by the authorities, some of them would then appear as waste.

For ACRO, this discharges aspect cannot be swept under the carpet as it constitutes a de facto acceptance of radioactive waste misleadingly hidden behind the term "clearance level" in the international texts.

In order to complete the information given to the readers, but also in order to adopt a truly umbrella approach to the waste issue, our association would have preferred to see a sub-chapter on effluent discharges – mentioning these discharge levels – in the 2016-2018 PNGMDR."

1.3 The legal and institutional framework of waste management

At the European level, Council directive 2011/70/Euratom establishes a community framework for the safe and responsible management of spent fuel and radioactive waste.

The national framework for the management of radioactive materials and waste is defined by the Environment Code and Programme Act 2006-739 of 28th June 2006 on the sustainable management of radioactive materials and waste. It covers the definition of a radioactive materials and waste management policy, improved transparency and democratic oversight as well as financing and economic support. It specifies that the management of radioactive materials and waste must comply with the following fundamental principles: to protect individual health and the environment; to prevent or mitigate the burdens to be borne by future generations; "polluter-pays" principle which takes precedence in environmental law.

The PNGMDR organises the performance of research and studies on the management of radioactive materials and waste in three directions:

- reducing the quantity and harmfulness of the waste, more specifically by reprocessing spent fuels and processing and packaging radioactive waste;
- storage as a preliminary step, in particular with a view to fuel and waste reprocessing operations or waste disposal;
- after storage, deep disposal as a long-term solution for ultimate waste which cannot be disposed of in surface or near-surface repositories for reasons of nuclear security or radiation protection.

With regard to transparency and democratic oversight, the Environment Code more specifically confirms the role of the National Review Board, tasked with evaluating research on the management of radioactive materials and waste. It also makes provision for regular debates by the High Committee for transparency and information on nuclear security.

1.3.1 International agreements

A Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management was established under the aegis of IAEA and approved by France on 22nd February 2000[20]. This Convention binds the 69 contracting States to set up a safe and sustainable system for managing radioactive waste and spent fuel. Peer reviews are held every three years on the basis of a national compliance report produced by each Member State[21].

Bilateral agreements can also be signed pursuant to Article L. 542-2-1 of the Environment Code, to deal with the procedures for the temporary import for processing of radioactive waste or spent fuels produced abroad. The agreements concluded by France concerning the management of spent fuel or radioactive waste are presented in Appendix 4.

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[20] It came into force on 18th June 2001.

[21] The 5th French report drawn up for the 2015 convention is available on the ASN website: http://www.asn.fr, following the links below: Accueil > L'ASN > International > Les textes de référence internationaux > Les conventions internationales > La Convention commune sur la sûreté de la gestion du combustible usé.

Information on materials and waste from abroad

Pursuant to Article L.542-1-2, the processing and research facility licensees establish, keep up to date and make available to the regulatory authorities the information concerning operations involving radioactive waste and spent fuels from foreign countries and the radioactive substances imported for research purposes. Each year they submit a report to the minister responsible for energy containing the inventory of the spent fuels and radioactive waste they hold originating from foreign countries and the radioactive materials and waste resulting therefrom after processing or processing or which result from research operations, and their forecasts concerning operations of this type. Every year, Areva[22] and CEA[23] produce these reports and make them public.

1.3.2 The European framework

In addition to the legislative provisions which were already present in France and in other countries of the European Union, directive 2011/70/Euratom establishing a community framework for the responsible and safe management of spent fuel and radioactive waste was adopted on 19th July 2011 by the Council of the European Union, to provide the Member States with a harmonised regulatory framework.

This directive defines a binding framework and requires that the Member States adopt a national policy for the management of spent fuel and waste, based more specifically on the following principles:

- polluter-pays, with the Member State having ultimate responsibility for the radioactive waste produced within its borders,
- minimisation of the volume and harmfulness of the radioactive waste produced;
- protection of the health of individuals, safety and the environment,
- disposal of waste in the country in which it was produced, except in the case of a bilateral agreement defined in accordance with the conditions of the directive.

The directive also requires the definition of a legislative framework and a national programme to implement a waste and spent fuel management policy according to a graded approach commensurate with the risk levels. This programme, which is based on a national inventory, must concern all waste, from production up to long-term management and must be periodically revised and notified to the European Commission.

This directive also requires that each Member State set up a regulatory authority with competence for the safe management of radioactive waste and spent fuel and with the financial and human resources necessary for the performance of its duties. It sets safety requirements and requires the creation of a system of authorisations for waste and spent fuel management facilities. It also requires those holding these authorisations to devote adequate financial and human resources to waste management.

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[22] See Areva report on the company's website: www.areva.com/FR/activites-1221/diffusion-de-l-information-areva-la-hague.html

[23] See CEA report on its website: www.cea.fr/multimedia/Pages/editions/institutionnel/inventaire-combustibles-uses-et-dechets-radioactifs-etrangers-rapport2016.aspx

The directive also stipulates that the necessary information concerning the management of spent fuel and radioactive waste must be made available to the public.

Finally, the directive requires regular self-assessment of the national framework, of the competent regulatory authorities and of the national programme and its implementation, supplemented by an international peer review.

This directive is a key factor in helping to strengthen nuclear safety within the European Union, while making the Member States more accountable for the management of their radioactive waste and spent fuels.

It constitutes a body of regulations consistent with:

- Council directive 2013/59/Euratom of 5th December 2013 setting basic standards for health protection against the hazards arising from exposure to ionising radiation, which more specifically requires the Member States to ensure that the elimination, recycling or reutilisation of radioactive materials resulting from an authorised practice be themselves subject to authorisation,
- Council Directive 2009/71/Euratom of 25th June 2009, amended, establishing a Community framework for the nuclear safety of nuclear installations.

1.3.3 The legislative framework in France

The objectives set by Council directive 2011/70/Euratom presented in the previous section are transcribed into French law.

Chapter II of title IV of book V of the Environment Code and the Programme Act on the sustainable management of radioactive materials and waste (Act 2006-739 of 28th June 2006)

The management of radioactive waste is governed by the 28th June 2006 Act on the sustainable management of radioactive materials and waste and its implementing decrees. This Act supplemented the provisions of Act 91-1381 of 30th September 1991. With the exception of its Articles 3 and 4, it is now codified in Chapter II of title IV of book V of the Environment Code.

The Environment Code sets out the following principles concerning the radioactive waste problem:

- it must be managed in such a way as to protect individual health, safety and the environment,
- the search for and implementation of management solutions must not be deferred, in order to prevent and mitigate the burdens to be borne by future generations,
- prime responsibility for the management of radioactive waste and spent fuel lies with their producers.

In accordance with the calendar determined by the 28th June 2006 Act, it requires continuation of the research policy, in particular for the management of long-lived, high or intermediate level radioactive waste, in compliance with the above-mentioned principles, along the following three complementary avenues of research:

- reduce the volume and harmfulness of the waste through partitioning and transmutation of long-lived radioactive elements. A review of the research carried out in this area is detailed in Chapter 4.2.3 of this Plan;
- make the waste permanently safe through reversible deep geological disposal. The law requires that Andra continue its studies and research pursuant to the 1991 Act and now requires that the concept developed by Andra be reversible. The law also sets milestones for the fundamental steps in the licensing process for a facility allowing such disposal to take place;
- ensure the safety of waste storage pending the availability of a final solution. The law requires that Andra carry out studies and research to create new storage facilities or modify the existing ones, in order to meet the needs identified by the PNGMDR, particularly in terms of capacity and duration, no later than 2015.

It also requires that waste produced before 2015 and not yet packaged, be packaged before 2030.

The Environment Code sets the framework for the management of all radioactive waste:

- by defining management guidelines[24] for all radioactive materials and waste, that is:
    - reducing the quantity and harmfulness of the radioactive waste, in particular by processing spent fuels and processing and packaging radioactive waste;
    - storage of radioactive materials pending processing and of ultimate radioactive waste pending disposal, in specially designed facilities;
    - after storage, deep geological disposal as a permanent solution for ultimate radioactive waste that cannot be disposed of the surface or at shallow depth, for nuclear safety or radiation protection reasons.
- by requiring the adoption every three years of a National Plan for Radioactive Materials and Waste Management (PNGMDR).

The Environment Code prohibits the disposal in France of radioactive waste produced in other countries. In particular, spent fuels or radioactive waste may only be brought into the country for a limited period for the purposes of processing, research or transfer between foreign States.

The Environment Code also specifies the steps involved in the creation and closure licensing process for a deep geological disposal facility. These steps more specifically comprise the prior operation of an underground laboratory in the zone concerned, a public debate and definition by law of the reversibility conditions. A review of the ongoing work on this subject is presented in part 4.2.

The Environment Code entrusts Andra with the responsibility for the long-term management of radioactive waste, in particular:

- to produce the national inventory of radioactive materials and waste in France,
- to collect, transport and take charge of radioactive waste from small producers outside the nuclear power generating industry,
- to make safe and rehabilitate sites polluted by radioactivity,
- to search for disposal solutions for all ultimate radioactive waste and operate and monitor the disposal facilities.

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[24] These management guidelines take account of the general management guidelines applicable to all types of waste defined in Article L. 541-1 of the Environment Code.

Finally, the legislative framework[25] makes provision for financing of the waste management system (see part 1.4), as well as for modernisation of the local support system for the underground laboratory and the future deep geological disposal facility.

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

The other legislative texts affecting the management of radioactive materials and waste

- Energy policy laws

The multi-year energy programming set out in Act 2015-992 of 17th August 2015 concerning energy transition for green growth, envisages various energy policy scenarios. Andra's National Inventory partly includes these scenarios in its 2015 edition and assesses their impact on the production of radioactive waste.

- Title IX of book V and Title II of book I of the Environment Code

Act 2006-686 of 13th June 2006 relative to transparency and security in the nuclear field ("TSN Act"):

- creates an independent nuclear safety regulator which takes part in the oversight of nuclear safety and radiation protection and in information of the public in these fields;
- deals with public information concerning nuclear safety: by reinforcing the right to information about nuclear facilities and creating a true legal framework for the local information committees (CLI) and by setting up a High Committee for transparency and information on nuclear security (HCTISN) designed to promote the national debate on the risks related to nuclear activities and on the impact of these activities on the environment and on individual health;
- sets up the legal system for BNIs and for the transport of radioactive substances, defining the conceptual framework and all the legal procedures applicable to these facilities and activities.

It is codified under Title IX of book V and Title II of book I of the Environment Code.

- The Public Health Code[26]

Article L. 1333-1 of the Public Health Code defines **nuclear activities** as activities involving a risk of human exposure to ionising radiation emanating from either an artificial source, or a natural source when the natural radionuclides are processed or have been processed owing to their radioactive properties. Nuclear activities also include measures taken to prevent or mitigate a radiological risk following an accident or contamination of the environment.

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[25] Articles L. 542-11 of the Environment Code and Article 43 of the 2000 Budget Act supplemented by the provisions of Article 21 of the 28th June 2006 Act.

[26] The articles of the Public Health Code concerning nuclear activities were modified by the ordinance of 10th February 2016 containing various nuclear provisions. Entry into force of these provisions will be deferred, but this will in any case take place before 1st July 2017. These modifications more particularly concern the inclusion of natural radioactivity and management of radon risks.

Nuclear activities are required to comply with the principles of:

- justification of the advantages gained by comparison with the risks involved;
- minimisation of human exposure to ionising radiation;
- restricting the doses received to below a threshold.

Pursuant to Article L. 1333-10 of the Public Health Code, the licensees of "non-nuclear" activities using materials containing natural radionuclides not used for their radioactive, fissile or fertile properties, must also take monitoring and protection measures appropriate to the risk of human exposure to ionising radiation. The same applies to owners or operators of premises open to the public, or certain categories of buildings constructed in geographical areas where exposure to naturally occurring radiation is liable to constitute a health hazard.

Certain regulatory provisions governing the above-mentioned activities have an impact on radioactive waste management.

Article L. 1333-7 of the Public Health Code also defines the principle of the responsibility of the radioactive waste producers with regard to management of the sealed radioactive sources [27] they distribute and which are intended for nuclear activities. Sealed radioactive sources, which are considered to be radioactive materials when distributed to the users, can be considered to be waste once they have been used. The suppliers are therefore required to recover them and present financial guarantees to cover the cost of their management in the event of defaulting.

1.3.4 The regulatory framework in France

The legislative framework for the management of radioactive materials and waste is specified by various Governmental decrees and orders. As required, ASN may clarify the provisions of these tests by means of statutory resolutions. It may also publish implementation guides or issue recommendations, which are not binding.

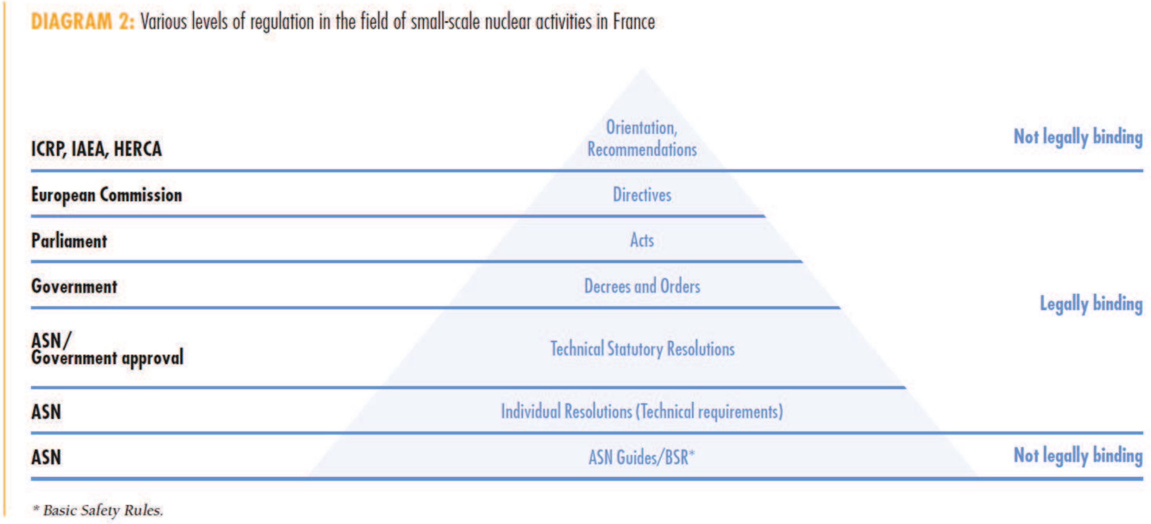

DIAGRAM 2: Various levels of regulation in the field of small-scale nuclear activities in France

ICRP, IAEA, HERCA	Orientation, Recommendations	**Not legally binding**
European Commission	Directives	**Legally binding**
Parliament	Acts	
Government	Decrees and Orders	
ASN/ Government approval	Technical Statutory Resolutions	
ASN	Individual Resolutions (Technical requirements)	
ASN	ASN Guides/BSR*	**Not legally binding**

* Basic Safety Rules.

The standards pyramid[28] - source ASN

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[27] Source for which the structure or packaging prevents all dispersion of radioactive materials into the ambient environment, in normal use.

[28] The guides and recommendations published by ASN are not binding.

In addition to the provisions concerning the PNGMDR which are described in section 1.3.5, special regulatory measures governing nuclear activities or installations with risks for human health as a result of exposure to ionising radiation are defined according to the quantity and activity of the radionuclides present.

By means of a graded approach, the regulations differentiate between three types of civil nuclear installations or activities:

- BNIs[29] which are linked to the type of installation and possibly as a function of the total activity of the radionuclides potentially present in the installation. They are placed under ASN oversight;
- ICPEs: below the BNI criteria but above certain thresholds, an installation using radioactive substances is regulated as an ICPE and placed under the oversight of the Prefects;
- activities handling radioactive substances which are not on the list of BNIs or ICPEs, are subject to the Public Health Code and subject to ASN oversight. These activities handle very small quantities of radioactive waste. This mainly concerns medical activities.

Basic Nuclear Installations

The BNI nomenclature is defined by Decree 2007-830 of 11th May 2007 relative to the Nomenclature of Basic Nuclear Installations. BNIs correspond more specifically to nuclear reactors, nuclear fuel storage facilities or radioactive waste disposal facilities, when the facility is capable of receiving radionuclides the potential stock of which would represent a total activity (expressed by a coefficient Q) exceeding a certain threshold. For example, this threshold is set at 10^9 for disposal facilities.

Decree 2007-1557 of 2nd November 2007, amended, concerning basic nuclear installations and the monitoring, from the nuclear safety viewpoint, of the transport of radioactive substances, and the order of 7th February 2012, amended, define the requirements applicable to the administrative procedures for the authorisation and operation of BNIs to protect the interests mentioned in Article L. 593-1 of the Environment Code (individual and public health and protection of nature and the environment). The management of the radioactive waste from BNIs is in particular taken into account.

Title VI of the Order of 7th February 2012 recalls the need for the licensee to take all necessary steps in the design and operation of its facilities to ensure optimum and safe management of the waste produced, in particular taking account of the management principles set out in the Environment Code and the available or planned management routes. The licensee is required to ensure the traceability of the waste it produces.

The licensee must also draw up a study specifying the management of the waste it produces and a waste zoning plan delimiting the areas within its installation where the production of nuclear waste is possible. ASN resolution 2015-DC-0508 of 21st April 2015 concerning the study of waste management and the review of waste produced in basic nuclear installations[30] specifies the

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[29] These facilities have counterparts in the defence sector: secret BNIs which are placed under the authority of the defence nuclear safety regulator (ASND).

[30] An ASN guide is being prepared to help the licensees implement this statutory resolution.

procedures for defining this waste zoning and states that waste from zones in which nuclear waste can possibly be produced must be managed as radioactive waste[31].

Defence Basic Nuclear Installations

The management of radioactive waste from secret BNIs (SBNI) is regulated by the order of 26th September 2007, setting the general technical regulations intended to prevent and mitigate off-site detrimental effects and risks resulting from the operation of secret BNIs; Title VI of this order recalls the need for the licensee to take all necessary steps to reduce the volume, radiological, chemical and biological toxicity of the waste produced in its facilities and to optimise its management, with preference being given to reuse and processing over final disposal, which is reserved for ultimate waste. It requires the drafting of a summary document specifying the management methods for the waste produced in the secret BNIs and the drafting of a waste zoning plan, delimiting the nuclear waste production zones in which all the waste must undergo specific, reinforced management (the nuclear waste must be collected, processed and eliminated in duly authorised facilities). This document is submitted to the Defence Nuclear Safety Authority (ASND) for approval and acts as the baseline for optimised management of the waste produced in the SBNI.

Installations Classified on Environmental Protection grounds

The installations liable to use more than 10 m^3 of radioactive substance and whose capacity would lead to a total activity (expressed by a coefficient Q) below the threshold mentioned in the BNI nomenclature, but exceeding 10^4, are subject to authorisation as an ICPE (section 1716)[32]. The installations in which more than one ton of solid residue of uranium, thorium or radium ore and processing products without uranium enriched in isotope 235 (heading 1735) are placed in disposal or storage, or the installations liable to manage more than 10 m^3 of radioactive waste with a total activity higher than the exemption thresholds defined by the Public Health Code (heading 2797) are also subject to authorisation as an ICPE pursuant to Decree 2014-996 of 2nd September 2014 modifying the nomenclature of installations classified on environmental protection grounds (codified in the Environment Code).

The licensee of such installations, generally corresponding to installations in the front-end of the fuel cycle or to very low level waste disposal facilities, must take all necessary steps to manage its waste in compliance with the legislative principles (reduction of volume and harmfulness, optimisation, etc.) specified in section 1.3.3. Article L. 541-7 of the Environment Code also states that these installations are required to provide the administration with all information concerning the origin, nature, characteristics, quantities, destination and elimination procedures for their waste.

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[31] Certain waste produced in these zones may however, subject to authorisation by ASN and after consultation of the public, be managed as non-radioactive waste if the licensee can demonstrate that it could in no way and at no moment have been contaminated or activated.

[32] Facilities of this type, for which the total activity may be between 1 and 10^4, require notification.

Other nuclear activities

With regard to the waste produced by nuclear activities outside a BNI, SBNI or ICPE[33] (medical nuclear activities in particular), Article R. 1333-12 of the Public Health Code and the ASN resolution of 29th January 2008 stipulate that the management of effluents and waste contaminated by radioactive substances, or liable to be so, comprising a risk of exposure to ionising ration, must undergo examination and approval by the public authorities.

As for BNIs, the authorisation holder must provide a management plan specifying the management of the waste it produces and a waste zoning plan delimiting the areas within its installation where the production of "contaminated waste" is possible. Waste from areas in which the production of contaminated waste is possible must be managed as contaminated waste. Very short-lived waste may be managed by means of radioactive decay, while the others must be managed in authorised routes.

Radioactive sources

Article R. 1333-52 of the Public Health Code requires that the suppliers of sealed radioactive sources recover any used source they have distributed, unconditionally and on simple request, or after a period of 10 years. In conditions compatible with the protection of health and the environment, the suppliers must have a storage site of sufficient capacity to take the sources once no longer used and pending their elimination (in a disposal facility) or their recycling. This same article requires that any party in possession of expired or end-of-life sealed radioactive sources must have them collected, regardless of their condition, by an approved supplier. Sources which cannot be recycled in current technical and economic conditions may as a last resort be collected by Andra. The costs relating to the recovery of these sources are to be borne by the party in possession.

The users and parties in possession of radioactive sources must:
- take all appropriate measures to prevent unauthorised access to them, loss, theft or damage by fire or water;
- be able to permanently justify the origin and destination of these sources;
- keep an inventory of sources and register them with the French Institute for Radiation Protection and Nuclear Safety (IRSN) prior to acquisition or transfer.[34]

1.3.5 The National Plan For Radioactive Materials And Waste Management

As mentioned in section 1.3.2, Article L 542-1-2 of the Environment Code requires the adoption every three years of a National Plan for Radioactive Materials and Waste Management (PNGMDR) which must:
- inventory the existing radioactive materials and waste management methods;
- identify the foreseeable needs for storage or disposal facilities and clarify the capacity needed for these facilities, as well as the storage durations.

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[33] Provisions applicable since 1st August 2015, the date of entry into force of the order of 23rd June 2015 concerning facilities utilising radioactive substances, radioactive waste or solid residues from uranium, thorium or radium ore, subject to authorisation under section 1716, section 1735 and section 2797 of the nomenclature of classified installations.

[34] See Articles R. 1333-50 and R. 1333-51 of the Public Health Code.

The PNGMDR must also:

- set the general targets, the main deadlines and the schedules enabling these deadlines to be met while taking into account the priorities it defines;
- determine the objectives to be met for radioactive waste for which there is as yet no final management solution;
- organise the implementation of research and studies on the management of radioactive materials and waste;
- determine the persons responsible for its implementation and the indicators for monitoring the progress of its implementation;
- include an estimate of the cost of management of the spent fuels and radioactive wastes, along with a schedule, and indicate the assumptions on which the estimate was established. The financing mechanisms in force must also be specified.

The PNGMDR must organise the research and studies to be conducted on waste management and set deadlines for implementation of new management methods and for the creation or modification of facilities. It must also include an inventory of the technical solutions and planned measures for the period after closure of the disposal facilities and a summary of achievements and of research carried out in other countries. The prescriptions of the PNGMDR are then confirmed by decree.

The following constitute inputs into the PNGMDR, which is produced by a pluralistic working group:

- Andra's national inventory of radioactive materials and waste;
- the studies and research carried out so far, in particular by the waste producers and Andra;
- ASN opinions and assessments by IRSN, the National Review Board, the Parliamentary Office for the Evaluation of Scientific and Technological Choices (OPECST), the HCTISN, etc.;
- consultation with all the stakeholders (radioactive waste producers and manager, administrations, members of local information committees, environmental protection associations, etc.), more specifically within a pluralistic working group;
- long-term dialogue with the populations around the radioactive waste management sites, in particular through the CLIs.

It covers all radioactive materials and waste and all stages in their management.

Each PNGMDR is transmitted to Parliament, which refers it to OPECST for evaluation and it is made public. A summary of the Plan intended for the general public is also published.

An innovation introduced pursuant to the provisions of Articles L. 122-4 and following of the Environment Code, is that this edition of the PNGMDR is subject to an environmental assessment[35], which is submitted for its opinion to the environmental authority of the general council for the environment and sustainable development in accordance with I of Article R. 122-17 of the Environment Code. The environmental assessment report on the PNGMDR and the opinion of the environmental authority are both made public.

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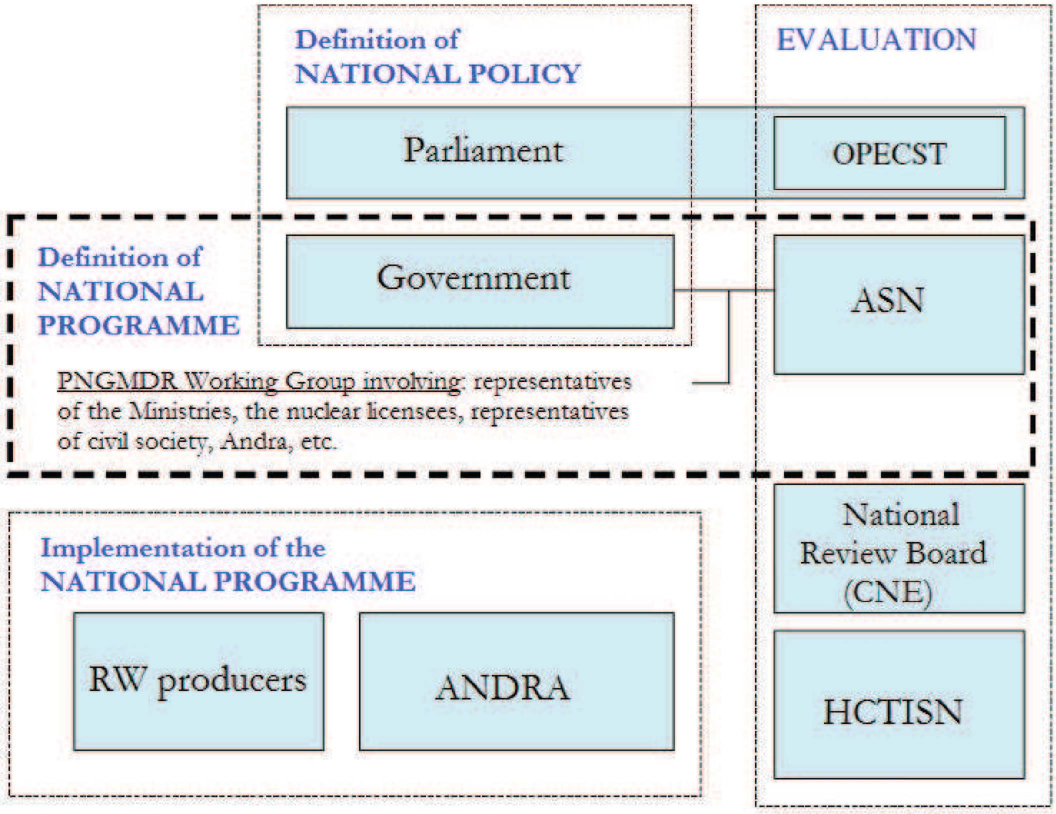
[35] The environmental assessment consists more particularly in identifying and evaluating the main effects of the Plan's measures on the environment, in presenting alternative measures envisaged to achieve the objectives of the Plan and explain why they were not adopted, and to indicate the steps to reduce and mitigate the negative impacts of the Plan on the environment.

Following on from the previous PNGMDR, the approach adopted for the revision of the PNGMDR thus places considerable emphasis on pluralism and transparency.

1.3.6 The stakeholders in radioactive materials and waste management

The responsibilities of the various stakeholders in the management of radioactive materials and waste are broken down according to the following diagram, which identifies three levels of management: definition of national policy ("principles and guidelines"), definition of the national programme ("measures to be taken"), implementation of this programme - and make a distinction between the entities in charge of implementing the national management system and those in charge of its assessment.



Drafting of French national policy, the national programme, implementation and assessment

<u>The producers of radioactive materials and waste</u>

The owners of radioactive materials and the producers of radioactive waste can be broken down into five economic sectors (see section 1.1.2): nuclear power generation, research, defence, industry unrelated to power generation and medical. Three producers: Areva, CEA and EDF account for more than three-quarters of all national production[36]. The producers are responsible for ensuring the management of the radioactive waste they produce until it is made safe once and for all.

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[36] See 2015 edition of the national inventory of radioactive materials and waste, produced by Andra.

French national radioactive waste management agency

Andra is a specialised public industrial and commercial organisation responsible for the long-term management of radioactive waste. The duties of Andra, detailed in Article L. 542-12 of the Environment Code, more particularly comprise the design and operation of disposal facilities, the performance of studies and research on storage and deep geological disposal, the collection, transport and processing of radioactive waste from the small producers unrelated to nuclear power generation, the remediation of polluted sites and information of the public. Andra drafts, updates and every three years publishes the inventory of radioactive materials and waste present in France.

The stakeholders in charge of drafting and implementing the national programme

Several Ministries are involved in defining, implementing and overseeing radioactive materials and waste management policy.

Within the Ministry for the Environment, Energy and the Sea, the General Directorate for Energy and Climate (DGEC) draws up policy and implements Government decisions concerning the civil nuclear sector, while the General Directorate for Risk Prevention (DGPR) and more specifically the Nuclear Safety and Radiation Protection Delegation (MSNR) drafts, coordinates and implements the Government's roles concerning civil nuclear safety and radiation protection, with the exception of the duties entrusted to ASN. Jointly with ASN, this delegation also follows up questions concerning the management of the former uranium mines and sites and soils polluted by radioactive substances. The DGPR also drafts conventional waste management policy, including waste referred to as NORM[37].

At the Ministry for Higher Education and Research, the General Directorate for Research and Innovation (DGRI) coordinates French research efforts.

There are two authorities in France for the oversight of nuclear safety and radiation protection:
- The Nuclear Safety Authority (ASN), an independent administrative authority, which regulates nuclear safety and radiation protection for civil nuclear facilities and activities. It provides secretariat services for the PNGMDR working group and issues opinions on the studies submitted within the framework of the PNGMDR;
- the ASND, headed by the nuclear safety and radiation protection delegate for defence-related activities and facilities, reporting to the Minister responsible for defence and the Minister responsible for industry, which oversees nuclear safety and radiation protection for defence-related activities and facilities.

The other participants or entities influencing the drafting of the national programme

In the exchanges organised to promote transparency and consultation, many other stakeholders are required to take part in defining radioactive materials and waste management policy. Thus representatives of civil society and of environmental protection associations such as ACRO (Association for the control of radioactivity in the west), Robin des Bois, GSIEN (group of scientists for information on nuclear energy), WISE-Paris (*World information service on energy*), Greenpeace or France Nature Environnement (FNE), take part in the PNGMDR working group.

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[37] Formerly referred to a technologically enhanced naturally occurring radioactive materials (TENORM).

Articles L. 125-34 to L. 125-40 of the Environment Code require that the HCTISN periodically organise consultations and debates concerning the management of radioactive materials and waste. The HCTISN may also be asked for its opinion on subjects regarding transparency and public information with respect to nuclear safety and its oversight and regulation.

Discussions also take place within:

- the CLIs, created for the nuclear installations (BNI and SBNI) and grouped into a national association of CLIs (ANCCLI);
- the local information and monitoring committee (CLIS), set up for Andra's Meuse / Haute-Marne underground laboratory.

When drafting certain aspects of radioactive materials and waste management doctrine, ASN may draw on the opinions and recommendations of an advisory committee of experts appointed for their competence in the field of waste[38]. The opinions of this advisory committee are made public by ASN.

Finally, international organisations are working on harmonising management policies between the various countries: EURATOM (European atomic energy community) and WENRA (Western European Nuclear Regulators' Association) at the European level, the NEA (Nuclear Energy Agency) of the OECD (Organisation for Economic Cooperation and Development) and the IAEA (International Atomic Energy Agency) reporting to the general assembly of the UN (United Nations).

The entities in charge of evaluating the national management programme

Within Parliament, OPECST carries out evaluations in order to inform Parliament of the consequences of the scientific and technological choices made. These evaluations may in particular concern the nuclear energy field. The role of Parliament and its long-term commitment must be underlined with regard to the oversight and definition of national policy for the management of radioactive materials and waste.

The National Review Board (CNE2) annually reviews research being performed on the management of radioactive materials and waste[39].

Radioactive materials and waste research organisations

In addition to Andra, the main French research institutes in the field of radioactive materials and waste management are CEA, the BRGM (geological and mining research office), CNRS (notably via the cross-disciplinary NEEDS: Nuclear, Energy, Environment, Waste, Society), INERIS (national institute for the study of industrial environments and risks), IRSN, the Institut Carnot MINES (French acronym for innovative methods for enterprises and society) and universities.

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[38] The experts (French and other countries) come from university and association backgrounds, but also include licensees or members of civil society concerned by the subjects addressed. The participation of experts from other countries can bring new approaches to problems and the benefit of international experience.

[39] The CNE2 reports are available on its website: http://www.cne2.fr/.

The 28th June 2006 Act more specifically entrusted responsibility for research on partitioning-transmutation to CEA and research on disposal and storage to Andra. IRSN focuses its research primarily on safety and radiation protection issues associated with waste management and geological disposal in particular. It contributes to maintaining a high-level of expertise enabling this Institute to act as a technical support organisation for the safety regulators.

At the same time, a certain number of R&D actions are performed by industry (EDF and AREVA), partly under agreements linking them to CEA or Andra.

These research programmes are monitored by a cycle back-end research steering and oversight committee chaired jointly by the DGEC and the DGRI, which aim to ensure that they are consistent.

1.4 The cost and financing of materials and waste management

Financing of the management of radioactive materials and waste is provided by the nuclear licensees, under State oversight, in accordance with the "polluter-pays" principle.

A system to ring-fence the financing of long-term nuclear costs was thus set up in the 28th June 2006 Act codified in the Environment Code. The licensees are required to evaluate the long-term costs, including the cost of decommissioning and the cost of managing spent fuels and radioactive waste. They are required to cover these future costs as of now, by setting up dedicated assets offering a high degree of security.

These operations are closely monitored by the State, through an administrative authority comprising the Ministers in charge of the economy and energy. To perform its oversight role, the administrative authority more particularly receives a three-yearly report from the licensees on the evaluation of the long-term costs, the methods and choices made for management of the dedicated assets, along with a quarterly inventory of these dedicated assets.

1.4.1 Legislative and regulatory provisions on the ring-fencing of financing of long-term costs

Application of the "polluter-pays" principle is particularly important in the financing of decommissioning operations and radioactive waste management. It is essential in order to avoid passing these costs on to future generations or to society as a whole, while it is we who today benefit from nuclear power generation. The 28th June 2006 Act thus introduced an arrangement to ring-fence the financing of long-term nuclear costs[40], supplemented in 2007 by a body of regulations.[41]

This arrangement is based on the creation of a portfolio of dedicated assets, as of commissioning of the facility and then gradually during the course of operation, managed in such a way that their sale allows the cost of the long-term operations to be financed as and when the time comes. This is done under the control of the State (administrative authority), which analyses the licensees' situation and can prescribe the measures necessary in the event of any insufficiency or inadequacy. In any case, the nuclear licensees remain fully responsible for the correct financing of the future cost of decommissioning their facilities or managing their waste.

The licensees of nuclear installations (BNI and SBNI) are thus required to make a prudent evaluation of the cost of decommissioning their facilities or, for radioactive waste disposal sites, the cost of final shutdown, upkeep and surveillance and monitoring[42]. They also evaluate the cost of managing their spent fuel and their radioactive waste. These costs must be covered by updated provisions recorded in the licensees' accounts. The licensees then create a portfolio of dedicated assets, allocated exclusively to covering their provisions, and the sale value of which is at least equal

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[40] The requirements of the 28th June 2006 Act, and more particularly its Article 2, are today partly codified (Articles L. 594-1 and following of the Environment Code).

[41] Decree 2007-243 of 23rd February 2007 (modified by decree 2010-1673 of 29th December 2010) and the order of 21st March 2007 modified relating to ring-fencing of financing for long-term costs.

[42] This evaluation also includes the costs of recovery and packaging of legacy waste (RCD).

to the amount of the provisions (except for those linked to the operating cycle[43]).

The dedicated assets must offer a sufficient and appropriate level of security, diversification and liquidity. Regulatory provisions therefore specify the asset acceptability rules (more specifically concerning the category of assets and the level of diversification of the portfolio).

Furthermore, the assets allocated to coverage of the provisions may not be used for any other purpose by the licensee and may not be the subject of any claim on the part of a creditor (including if the licensee is experiencing financial difficulties), with the exception of the State in the exercise of its powers, to ensure that the licensees meet their obligations with respect to decommissioning and to the management of radioactive materials and waste. The assets must be the subject of a quarterly inventory.

Since June 2011, the licensees have been required to permanently maintain the coverage level of their provisions above the 100% threshold.

Since 2015, the obligation to set up financial guarantees has also been extended to licensees of ICPEs utilising radioactive substances[44]. These guarantees aim to ensure monitoring of the sites, keeping the facilities safe and response measures in the event of an accident.

Article L. 542-1-2 of the Environment Code states that the PNGMDR *"includes an estimate of the cost of management of the spent fuels and radioactive waste, along with a schedule, and indicating the assumptions on which the estimate was established."* In order to supplement the information available in the 2016-2018 PNGMDR on the cost of management of radioactive waste, the parties in possession of spent fuels must provide data on their current management costs.

R3 – Before 31st December 2017, Areva, EDF and CEA transmit data on the detailed management costs of all types of spent fuels and radioactive waste in their possession, more particularly including transport, storage and possible processing costs. For spent fuels from naval propulsion systems, only metal spent fuels are concerned by this request.

1.4.2 Licensee oversight procedures

Licensee compliance with their obligations is monitored by an administrative authority, formed jointly by the Ministers responsible for the economy and for energy. At an administrative level, this monitoring is performed by the DGEC, which calls on the expertise of the competent nuclear safety regulators (ASN and ASND).

Under the terms of the Environment Code[45], the licensees send the administrative authority a report, every three years, describing their evaluation of the long-term costs, the methods applied to calculate the provisions corresponding to these costs and the choices made with regard to the

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[43] The above-mentioned order of 21st March 2007 specifies that only the cost of managing spent fuels that can be recycled in the industrial facilities built or under construction can be considered as linked to the operating cycle, as defined in Article L. 594-2 of the Environment Code (formerly article 20-II of the 28th June 2006 Act).

[44] Order of 23rd June 2015 concerning facilities utilising radioactive substances, radioactive waste or solid residues from uranium, thorium or radium ore, subject to authorisation under section 1716, section 1735 and section 2797 of the nomenclature of classified installations.

[45] See Articles L. 594-1 and following of the Environment Code.

composition and management of the assets allocated to coverage of the provisions. An update of this report must also be transmitted annually, as well as on the occasion of any event entailing a substantial modification of its content. Finally, the licensees send the administrative authority a quarterly inventory of the dedicated assets.

If the administrative authority identifies any insufficiency or inadequacy in the evaluation of costs, the calculation of the provisions or the amount, the composition or management of the assets allocated to these provisions, it may – after hearing the licensee's observations - prescribe the steps necessary for remedying the situation, setting deadlines for compliance. In setting these deadlines, the administrative authority takes account of the economic conditions and the situation of the financial markets. These deadlines may not exceed three years.

If these requirements are not met within the allotted time, the administrative authority may order the creation of the necessary assets as well as all and any measures concerning their management. The administrative authority may also impose a financial penalty, the amount of which cannot exceed 5% of the difference between the value of the assets put into place by a nuclear installation licensee and that stipulated by the administrative authority. If the licensee fails to meet its information obligations, the administrative authority may impose a financial penalty of up to €150,000.

Moreover, if the administrative authority observes that there could be an obstacle to the application of the legislative provisions, it may require that the licensee concerned pay the necessary sums into a fund set up with Andra (Article 542-12-2 of the Environment Code).

In recent years, staffing levels at the administrative authority have been gradually consolidated to take account of the considerable workload involved in oversight of the long-term costs. The audit programme mentioned in the 2012 report from the CNEF[46] (national evaluation commission for financing the cost of decommissioning of basic nuclear installations and of managing spent fuels and radioactive waste) has been initiated, with the aim of providing the administrative authority with external analyses of the long-term costs.

The ACPR (French prudential supervision and resolution authority) may be consulted by the administrative authority on financial problems linked to compliance with the assets creation obligations incumbent upon the nuclear licensees. The government thus envisages shutting down the CNEF, as already suggested by itself in its 2012 report.

1.4.3 Amounts of provisions and dedicated assets

For the three main licensees (Areva CEA, EDF), as at 31st December 2011, the following table shows:

- the gross long-term costs in 2014 economic conditions, *i.e.* the amount that would have had to be spent if all the works were carried out in 2014;
- the corresponding provisions updated according to the anticipated expenditure schedules;
- the amount of the share of these provisions which must be covered by dedicated assets as required by law;
- the value of the assets already in place.

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[46] This commission, set up by Article L. 594-11 of the Environment Code, is chaired by members of Parliament and reports to Parliament.

In billions of euros, and as at 31.12.2015		Gross costs, in 2014 economic conditions	Updated provisions	Provisions to be covered by dedicated assets [47]	Value of coverage assets portfolio	Coverage percentage
EDF	Decommissioning	26.1	14.9	14.9	-	-
	Fuels	20.6	12.9	0.4		
	Waste	28.9	8.3	8.3		
	TOTAL	**75.6**	**36.1**	**23.6**	**23.5**	**99%**
CEA	Decommissioning	10.1	7.1	7.1	-	-
	Fuels	1.4	0.7	0.7		
	RCD*	3.6	2.6	2.6		
	Waste	6.5	2.5	2.5		
	TOTAL	**21.6**	**12.9**	**12.9**	**13.4**	**103%**
AREVA and subsidiaries	Decommissioning	8.9	4.4	4.4	-	-
	RCD*	1.5	1.2	1.2		
	Waste	3.1	1.2	1.2		
	TOTAL	**13.5**	**6.8**	**6.8**	**6.4**	**95%**
Total Licensees	Decommissioning	45.0	26.4	26.4	-	-
	Fuels	22.0	13.6	1.1		
	RCD*	5.1	3.9	3.9		
	Waste	38.5	12.0	12.0		
	TOTAL	**110.5**	**55.9**	**43.4**	**43.3**	**100%**

Dedicated assets of licensees Areva, EDF and CEA as at 31st December 2015[48].

** RCD: recovery and packaging of legacy waste*

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[47] Only the provisions for decommissioning, the provisions for radioactive waste management and the provisions for non-recyclable spent fuel management are to be covered by dedicated assets. The provisions for the management of spent fuel that can be recycled in industrial facilities already built or under construction are excluded from coverage, even though they must be accounted for in the provisions in accordance with Article L. 594-1 of the Environment Code. The corresponding costs will be directly financed by the operating income from the industrial facilities already built or under construction.

[48] The data provided in this table are taken from the 2015 updates from Areva, CEA and EDF of the three-yearly report on the ring-fencing of financing of nuclear costs.

1.5 Transparency

Transparency, information, debate and public consultation are an essential cornerstone of radioactive materials and waste management policy, which consists in ensuring that there is democratic dialogue at all levels:

- at the local level, continuously within the local information committees;
- at Parliamentary level, concerning the modes of final management of high and intermediate level, long-lived waste, with evaluation of the national management system and the progress it has made;
- with the general public, via the PNGMDR and public debates.

In this process of transparency, information and public consultation concerning the decision-making process for the management of radioactive materials and waste, all the work concerning the drafting and follow-up of the PNGMDR carried out within a pluralistic working group is made public (studies and research prescribed by the previous plan, opinion on studies, minutes of meetings, environmental assessment report, presentations, etc.).

1.5.1 Information and participation of the public

One of the cornerstones of the radioactive materials and waste management policy is to ensure the existence of a democratic dialogue at all levels:

- continuously at the local level, by setting up CLIs for the processing and disposal facilities;
- with the general public: the PNGMDR, based on the national inventory of radioactive materials and waste, is a key factor in transparency. In addition, France may also need to resort to national public debates. A debate on the management of radioactive waste was thus held for 4 months in 2005, ahead of the "Waste" Act of 28th June 2006. Another debate on the Cigeo reversible deep geological disposal project was held for 6 months in 2013;
- at Parliamentary level: with regard to the authorisation of a deep geological disposal facility, the Waste Act makes provision for two Parliamentary decisions, the first to set the reversibility conditions prior to authorisation of the disposal facility and the second, more long-term, to authorise its closure. The final creation authorisation decision will lie with the Government, but the authorisation decree for a disposal facility may only be issued if previously examined by Parliament.

Articles L. 124-1 and following of the Environment Code stipulate the right of all individuals to gain access to environmental information in the possession of, received by, or produced by the public authorities. All the information held is thus accessible to the public, except for that compromising industrial confidentiality or which could constitute a threat to public security.

The Environment Code defines transparency and the right to information on nuclear matters as a range of measures taken to guarantee the public's right to reliable and accessible information relating to nuclear security. The right to information on nuclear security and radiation protection more specifically concerns public information about events which have occurred in nuclear facilities or during transportation of radioactive substances, about discharges and accidental releases from nuclear facilities and worker and patient information about their individual radiological exposure levels.

Structures and procedures to allow public participation have been put into place. These are consultation, dialogue, information and debating bodies:

- the HCTISN;
- the CLIs, represented at the national level by the national association of local information committees (ANCCLI);
- the pluralistic working group in charge of drafting and following up the PNGMDR.

Several public consultation procedures actually used in the decision-making process concerning radioactive waste management, are governed by the regulations:

- public consultation about draft public decisions with an impact on the environment, pursuant to Article L. 120-1 of the Environment Code;
- public inquiries for licenses or license modifications concerning the facilities;
- public debate on development or public works projects with a major impact on the environment or land use, above a certain investment level (which is the case of the Cigeo project, detailed in section 4.2.6).

Public information is also carried out directly by the various radioactive materials and waste management stakeholders, more particularly via their websites.

1.5.2 The work of the PNGMDR working group

Radioactive materials and waste must be managed in a manner that is transparent for the public and involves all the stakeholders. The PNGMDR is thus produced by a pluralistic working group[49] co-chaired by ASN and the DGEC.

This PNGMDR working group meets every quarter. These meetings are an opportunity for technical discussions on subjects related to radioactive materials and waste management. Their purpose is:

- to monitor the actions defined by the plan in force and its implementation decree;
- to inform the members of the working group about subjects relating to radioactive materials and waste management;
- to provide input for the three-yearly revision of the plan.

In order to facilitate the debates, thematic working groups supplement the work of the plenary group. The associations are effectively represented within these thematic groups, which periodically report to the plenary session on the work done.

The PNGMDR, its summary and the decree stipulating the prescriptions of the Plan, as well as the ASN opinion on the studies submitted within the framework of the PNGMDR, are made public and are available on the website. In addition, since the June 2014 meeting of the working group, the presentation media and minutes of the plenary sessions have been available on-line on the

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[49] The PNGMDR working group consists in particular of representatives of the administration, the safety regulators, the radioactive waste managers, the producers of waste and representatives of associations and of civil society.

websites of ASN[50] and the Ministry for Energy[51]. The studies submitted by the licensees, which had already been transmitted to the members of the PNGMDR working group, will also be published provided that they do not contain anything the licensees do not wish to divulge, for justifiable confidentiality reasons.

Moreover, the distribution of the environmental assessment of this PNGMDR and the opinion of the corresponding environmental authority, will also contribute to public information and help obtain a broader spectrum of public comments.

Finally, any irreconcilable points of disagreement between the members of the working group, are stated in the PNGMDR.

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[50] http://www.asn.fr.

[51] http://www.developpement-durable.gouv.fr/-Energie-Air-et-Climat-.html.

2 The management of radioactive materials

A radioactive material is defined as a radioactive substance for which further use is planned or envisaged, if necessary after processing. These materials may be used in France or in other countries. The 2016-2018 PNGMDR presents the ways in which the effectively reusable nature of these materials is assessed, their traffic volumes and stocks at the various steps in the fuel cycle as well as their reutilisation routes.

The main radioactive materials are the following:

- those from the uranium/plutonium technology and comprising:
    - **uranium**, which has four separate sub-categories:
        - **natural uranium**, used by the enrichment plant to produce two separate substances: enriched uranium and depleted uranium;
        - **enriched uranium**, intended mainly for the fabrication of fuel to produce nuclear generated electricity;
        - **depleted uranium**, which is used to manufacture **MOx fuel** (mixture of uranium and plutonium oxides) and which can be used in 24 NPP reactors operated by EDF; some of it may be re-enriched with isotope 235 and thus be used in place of natural uranium; in the longer term, it could be used on a large scale according to the designers of generation IV fast neutron reactors;
        - **recycled uranium from processed spent fuels (URT)**, which can, according to the economic conditions, be re-enriched to produce **enriched recycled uranium (URE)** used to make URE fuels which can be utilised by the Cruas reactors in France;
    - **plutonium**: contained in spent fuel assemblies and extracted when they are processed. It is used to manufacture MOx fuels;
    - **spent fuels,** with most of the traffic consisting of uranium oxide (UOx) based spent fuels. The technical feasibility of reprocessing most of the spent fuels present on French soil has been demonstrated, but only UOx fuels are currently being processed on an industrial scale.
- **thorium**: which could be used in various types of reactors as a fuel in the thorium cycle, but not for several decades yet, given the R&D work still needed. Other applications are under development, in particular for the treatment of certain cancers or for its use in existing technology NPP reactors in addition to the uranium-plutonium cycle.

The 2016-2018 PNGMDR asks that the potential scenarios for the next editions of the National Inventory of radioactive materials and waste be developed further, more particularly to take account of the effective possibilities for reutilisation of the materials and to incorporate their inter-dependence with the envisaged or existing outlets.

Within the framework of the studies requested by the 2013-2015 PNGMDR, the owners of radioactive materials provided studies on the management options if the materials were to be reclassified as waste at some time in the future. **The 2016-2018 PNGMDR requests that these studies be taken further by Andra, jointly with the producers, with regard to depleted uranium, URT and thorium.**

2.1 *Context and issues*

As specified in Article L. 542-1-1 of the Environment Code, a radioactive material is defined as being a radioactive substance for which further use is planned or envisaged, if necessary after processing.

The classification of a radioactive substance in this category is thus decided on by its owner. The State may reclassify materials as waste if its further use prospects are not sufficiently well-established. This choice is in particular made according to the existing utilisation or the envisaged industrial prospects.

Radioactive materials are more specifically intended for use in the nuclear power generating industry and the anticipation of fuel cycle requirements is essential to ensure that the nuclear power plants (NPP) are correctly supplied and that the materials are managed safely pending utilisation. In this respect, the producers aim to ensure the availability of a sufficient and suitable stock of radioactive materials, sufficient capacity in the facilities intended for the storage of these materials and the necessary diversification of procurement sources and cycle facilities (conversion, enrichment, fabrication and processing of fuels) to remedy any unforeseen events and operational failures that could interrupt production. Radioactive materials are exchanged with other countries at several steps in the fuel cycle, even when France has the necessary expertise[52].

At present, the main categories of radioactive materials identified are uranium (naturel, depleted, enriched and reprocessed), uranium oxide based fuels (UOx and URE), uranium and plutonium oxide based fuels (MOx, MOx scrap and fuels from the Superphenix and Phenix fast neutron reactors), research reactor fuels, plutonium and thorium. Sealed radioactive sources (new or used pending recycling) can also be included. The national inventory presented in section 1.1.4 of this PNGMDR identifies about 350,000 t of radioactive materials as at the end of 2013 and foresees a stock of 510,000 t by the end of 2030 (with depleted uranium accounting for 80% of the stock by mass).

To ensure the overall consistency of the radioactive materials management system, the foreseeable storage facility needs are identified by the PNGMDR in accordance with Article L. 542-1-2 of the Environment Code. On this basis, the plan specifies the deadlines for the creation or modification of these facilities, along with their necessary capacity and the corresponding storage durations. Aspects concerning the fuel cycle are also more broadly examined by ASN in a "cycle impact" file[53] which presents a forward-looking approach to monitoring of the fuel cycle, primarily to ensure its continuity.

Similarly, to ensure safety and compliance with the principle of prevention and mitigation of the burdens to be borne by future generations, as set out in Article L. 542-1 of the Environment Code, the fate of radioactive substances considered to be radioactive materials by their owners must be periodically examined. If serious doubts were to arise with regard to the possible further use of a radioactive substance, it is necessary to ensure that the required guarantees, financial in particular, are in place to handle these substances in dedicated management routes up to and including disposal. The legislative framework more specifically allows the State, on the advice of ASN, to

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[52] For example, while still primarily utilising AREVA, EDF has contracts with Urenco (enrichment company located in the Netherlands, Great Britain and Germany) and with Tenex (company located in Russia) which also have expertise in ultracentrifuge enrichment techniques.

[53] The data concerning the "2007 cycle impact " file are available on the ASN website: http://www.asn.fr, headings « les actions de l'ASN », « les appuis techniques », « les groupes permanents d'experts », « groupe permanent d'experts pour les déchets ». This file will be updated in 2016.

reclassify radioactive materials as radioactive waste[54]. Studies[55] are also periodically requested for interim examination of the possible management routes should the materials be reclassified as waste in the future, primarily in the eventuality of the nuclear power generating programmes being discontinued either in France or in other countries.

A reassessment of the actually reusable nature of the radioactive materials was requested in the 2013-2015 PNGMDR and in Decree 2013-1304 of 27th December 2013 defining its prescriptions. The owners of radioactive materials, Areva, CEA, EDF and Solvay, submitted their updates of the envisaged reutilisation processes[56] and provided their analysis of the balance between the reutilisation prospects and the current and future quantities held. These data were the subject of an opinion by ASN and ASND[57] which will constitute a basis for the recommendations and outlook of this plan on this subject.

This chapter also describes the current or envisaged management routes for radioactive materials held on French soil. It inventories the traffic and stocks of these materials, more particularly specifying the additional storage capacity required to meet foreseeable growth in stocks. It describes the criteria to be considered when evaluating the reusability of these materials and presents the conclusions resulting from the reassessment conducted in the 2013-2015 PNGMDR.

2.1.1 Presentation of the fuel cycle

In France, EDF operates a standardised fleet of 58 PWR (pressurised water reactors). These reactors are supplied with fuel in the form of uranium oxide, slightly enriched with isotope 235 or in the form of a mixture of plutonium and uranium oxides. On average, the fuel supplies the reactor for 3 to 5 years and fuel management is staggered. Every 12 to 18 months, the fuel is unloaded: the oldest elements are replaced by new ones and the others are repositioned in the reactor core after reloading.

The **fuel cycle** designates all the industrial operations associated with the supply of new nuclear fuel assemblies for the nuclear generation of electricity (cycle front-end) and with the management of these assemblies after burn-up in the reactor (cycle back-end). The cycle front-end comprises: procurement of natural uranium (mines), conversion (or fluorination), enrichment and manufacturing of fuel elements, along with the corresponding logistics. The cycle back-end comprises: storage of spent fuels, their processing, manufacturing of fuels from separated materials,

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[54] See Article L. 542-13-2 of the Environment Code.

[55] The work submitted pursuant to the 2010-2012 PNGMDR concerned depleted uranium, URT and thorium. Additional work on these substances is expected before the end of 2019 pursuant to the guidelines of this present PNGMDR.

[56] Except for processes concerning nuclear materials allocated to the means necessary for implementing the deterrent policy mentioned in Article L. 1333-1 of the Defence Code, in accordance with the requirements of the 2013-2015 PNGMDR.
The report submitted by Areva, CEA, EDF and Solvay pursuant to the 2013-2015 PNGMDR is available on the websites of ASN and the Ministry responsible for energy:

- http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015 ;
- http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

[57] ASN opinion 2016-AV-0256 of 9th February 2016 concerning the evaluation of the actually reutilisable nature of the radioactive waste is available on the website: http://www.asn.fr, headings « les actions de l'ASN », « la réglementation », « bulletin officiel de l'ASN », « avis de l'ASN ». The ASND returned its opinion on 29th April 2016.

and the corresponding logistics plus management of the ultimate long-lived waste resulting from processing.

Fuel cycle front-end

The **procurement of natural uranium** by mining of uranium deposits uses traditional methods. The uranium ore extracted from the mines (underground, open-cast or by in-situ leaching) is chemically treated (concentration and purification) to form a solid uranium concentrate containing 70 to 80% uranium (uranates or oxides), commonly referred to as "yellow cake".

The **conversion** operation consists in transforming the natural uranium concentrates into uranium hexafluoride (UF_6), a chemical form that is required for the enrichment stage in the process used (centrifuging). This operation is carried out in France in two steps: first of all on the Areva NC Malvési site, where the uranium ore concentrates are finely purified and converted into uranium tetrafluoride (UF_4) and then on the Tricastin site, where the UF_4 brought in is transformed into UF_6.

The uranium isotopic **enrichment** step consists in increasing the natural concentration of uranium 235 from 0.71% to a value of between 3 and 6%. On leaving the enrichment facilities, two fractions are recovered: the enriched uranium and the depleted uranium with a uranium 235 content (also called depleted tails) usually varying between 0.2 and 0.3% depending on parameters relating to the cost of enrichment and the cost of the material.

The **fuel elements fabrication step,** comprises the following individual operations: thermal deconversion (transformation of UF_6 into UO_2), thermal pelletising (compacting and sintering), rod fabrication and assembly.

For each step in the cycle front-end, EDF calls on several suppliers. The French plants in the cycle front-end currently in operation, in particular for the needs of EDF, are the two conversion plants on the Malvési and Tricastin sites, the GB2 enrichment plant operated by SET (Société d'enrichissement du Tricastin) on the Tricastin site and the Romans-sur-Isère fuel fabrication plant operated by Areva NP.

Fuel cycle back-end

In accordance with the guidelines[58] given in Article L. 542-1-2 of the Environment Code, EDF carries out processing-recycling of some of the spent fuels it produces on French territory, in order to recover the fissile material (uranium and plutonium) it contains (96%) with a view to reusing it in the form of new fuels.

The **processing** of spent fuel assemblies comprises a range of mechanical and chemical operations, the purpose of which is to separate and extract the reusable materials (uranium and plutonium) from the rest of the elements (fission products, minor actinides and metal materials making up the structure of the fuel assemblies), which are then duly packaged and constitute ultimate waste. EDF fuels are rprocessed in the two Areva NC plants on the La Hague site (UP2-800 and UP3-A), which output: plutonium in the form of PuO_2, processed recycled uranium (URT) in the form of uranyl nitrate[59] and ultimate residues to be sent for disposal.

The **recycling** of spent fuels consists in reusing the radioactive materials they contain (uranium and plutonium) in the fabrication of new fuel products, which can be based on uranium and plutonium oxide (MOx fuel) or based on re-enriched recycled uranium (URE). In 2015, of the 58 reactors operating in France, 24 units[60] of 900 MW are authorised to run with MOx fuel, manufactured in the Areva NC MELOX plant on the Marcoule site. Only the four 900 MW units on the Cruas NPP can operate with URE fuel, but EDF has suspended this recycling since 2013.

Storage pending a final disposal solution concerns ultimate waste from the spent fuels processing carried out in the la Hague plants:

- the metal materials making up the spent fuel assembly structure (hulls and end-pieces) are isolated, decontaminated and then compacted and packaged in the form of standard compacted waste packages (CSD-C);
- high-level solutions, containing fission products and minor actinides, separated from the uranium and plutonium, are concentrated, sintered and then vitrified and packaged in standard vitrified waste packages (CSD-V).

These wastes (CSD-C and CSD-V) are long-lived and currently stored on the La Hague site in dedicated facilities, pending a final disposal solution.

The storage of radioactive materials pending their further use concerns UOx, URE and MOx spent fuels, as well as depleted uranium[61] and URT. The prospects for the use of these materials are presented in Chapter 2.2 of this part.

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[58] A reduction in the quantity and harmfulness of the waste must be sought, in particular by reprocessing spent fuels and processing and packaging radioactive waste.

[59] Uranyl nitrate is converted into a solid and stable compound U_3O_8 in AREVA's TU5 unit on the Tricastin site and is then stored on this site pending the subsequent utilisation envisaged by EDF.

[60] These reactors can contain up to 30% MOx fuel, the rest being made up of conventional uranium oxide based fuel assemblies. The MOx fuel is obtained by mixing PuO_2 with a UO_2 matrix made from depleted uranium; the powder is then made into pellets, turned into rods and then assembled using a process appreciably the same as that used to fabricate "conventional" uranium oxide assemblies. The MOx contains about 8.5% plutonium and 91.5% depleted uranium. It produces the same energy as a "conventional" uranium oxide fuel.

[61] The stock of depleted uranium is created in the front-end part of the cycle, during the uranium enrichment step.

The approximate annual traffic of radioactive materials and waste in the French fuel cycle is shown in the following table.

Approximate annual traffic in the French fuel cycle[62] as of 2015	
Natural uranium	~ 7 000 tU
Enriched uranium	~ 1 000 tU
Depleted uranium	~ 6 000 tU
Loaded UOx fuels	1 075 t_{HM}
Loaded MOx fuels	125 t_{HM}
Nuclear electricity production	420 TWh
Unloaded spent fuels	1 200 t_{HMi}
UNE processing traffic	1 100 t_{HMi}
Recycled plutonium	11 t_{HM}
URT	1 045 tU
CSD-C	715 packages
CSD-V	825 packages

All the steps in the fuel cycle, summarised in the following diagram, are closely interconnected: each of these operations must therefore be planned and performed so that it is compatible with the following ones and in such a way as to ensure overall optimisation.

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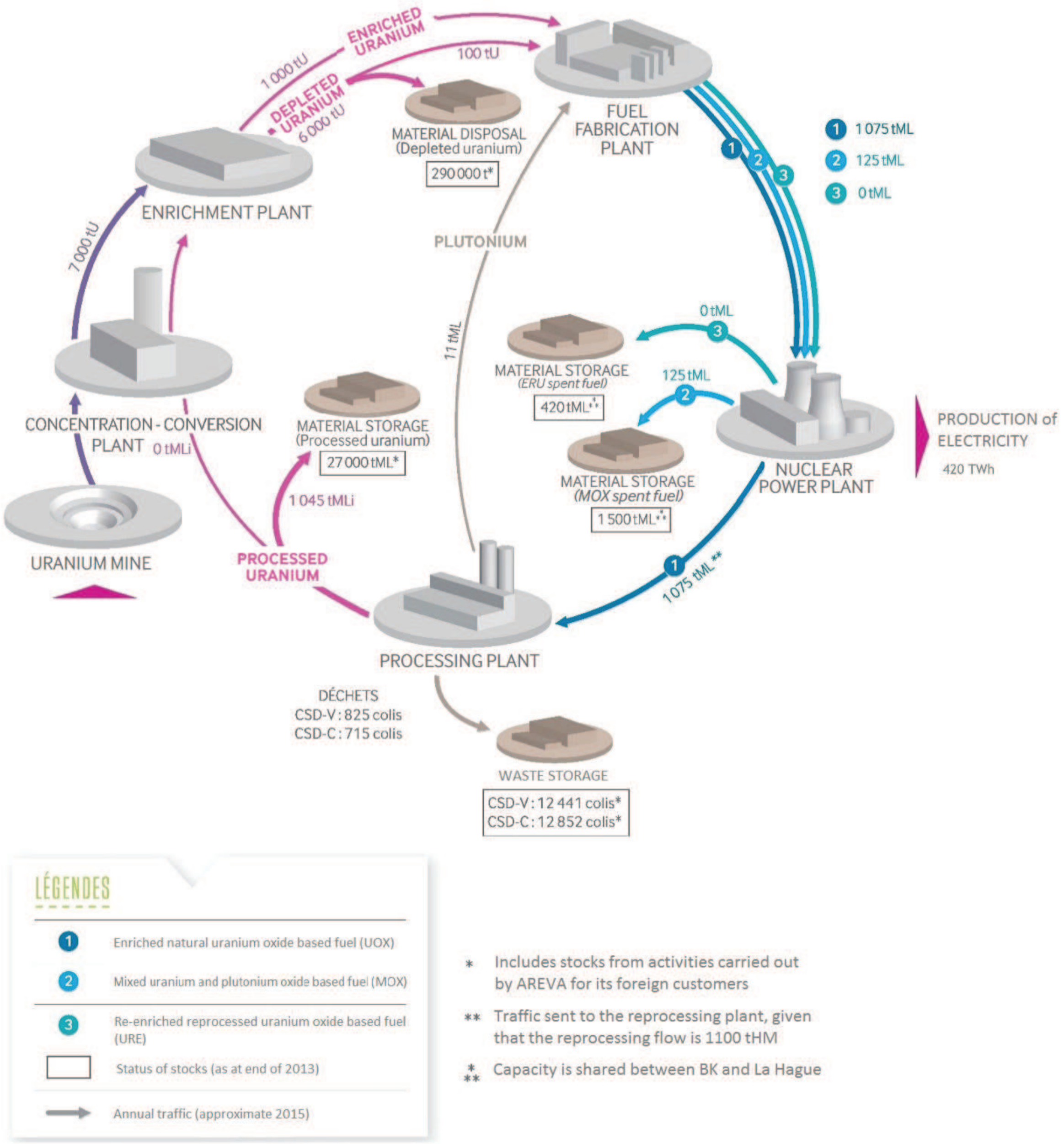
[62] The annual traffic does not include all the activities performed by AREVA on behalf of its foreign customers (except EDF), nor the traffic linked to research reactors (see section 2.2.4)



* Includes stocks from activities carried out by AREVA for its foreign customers

** Traffic sent to the reprocessing plant, given that the reprocessing flow is 1100 tHM

*** Capacity is shared between BK and La Hague

2.1.2 Inventory of materials traffic and stocks

Radioactive materials are exchanged with other countries at several steps in the fuel cycle. Since 2001, France has no longer worked domestic uranium mines and it procures natural uranium exclusively on the international market. Natural uranium is distributed relatively uniformly around the world, which allows significant diversification of supply sources. The French nuclear operators thus procure mainly from Kazakhstan, Niger, Canada, Australia and Uzbekistan. Areva NC has already acquired ownership rights to several uranium deposits (Canada, Niger, Kazakhstan, etc.). The stock of depleted uranium held in France by Areva can also be re-enriched if necessary to manufacture UOx fuels. This stock represents a natural uranium equivalent of about 50,000 t, corresponding to about 7 years of operation of the NPP fleet operated by EDF[63].

EDF has diversified its suppliers at each step in the fuel cycle, more specifically to safeguard its fuel supplies. To avoid any interruption in supply and while still calling on Areva, EDF also has contracts with Converdyn (USA), Cameco (Canada) and Tenex (Russia) for uranium conversion, with Urenco (Netherlands, United Kingdom and Germany) and Tenex (Russia) for enrichment and with Westinghouse (USA - Japan) for fuel fabrication. This policy of diversification entails exchanges of materials (natural, depleted and enriched uranium) with other countries.

The plutonium traffic reflects Areva's commercial activity in the la Hague plant. It comprises on the one hand the arrival of spent fuels at the La Hague plant under processing contracts between Areva and its foreign customers and, on the other, the shipment of MOx fuels to these same customers.

The thorium traffic is linked to the activities of the Solvay company.

In 2009, the Minister responsible for energy and the OPECST contacted the HCTISN concerning the question of the international exchanges involved in uranium processing and asked it for its opinion on the management of radioactive materials and waste produced at the various stages of the fuel cycle.

The HCTISN submitted its report in July 2010[64]. It presents a detailed analysis of the fuel cycle as it existed in France at that time. It gives the traffic and stocks of materials and waste produced at the various stages in the fuel cycle, as well as the conditions for the storage and transport of depleted uranium and recycled uranium produced by the processing of spent fuels, while presenting the issues involved in the supply of uranium and France's policy for ensuring the security of these supplies in an international context. The last part of this report is devoted to the quality of the information delivered to the public. Finally, the High Committee makes recommendations for improving the transparency and quality of the information provided to the public.

Pursuant to the recommendations made by the HCTISN[65], the Ministry responsible for energy sends the High Committee an annual inventory of traffic and stocks of materials produced at the various stages of the fuel cycle. These data are summarised in the following tables with regard to cross-border exchanges of materials. The year-on-year variations observable are partly short-term, to a certain extent linked to the nature of the exercise. This review freezes the status of the traffic as at 31st December of each year and can thus show considerable variations if certain industrial operations overlap two consecutive years.

The main trends observable in recent years can be explained by three main factors: the cessation of the Areva NC contracts with Tenex, the closure of the FBFC site in Dessel in Belgium and the end of exchanges between Eurodif and the various Urenco sites.

The gradual termination of the Areva NC contracts with the Russian Tenex company since 2010 helps explain the significant drop in depleted uranium exports. In 2010, Eurodif (subsidiary of Areva) exported about 4,000 t of depleted uranium to Tenex and this contract was completely terminated in 2014.

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[63] On the basis of an annual requirement of 7,000 t of natural uranium.

[64] The complete HCTISN report is available on the website: http://www.hctisn.fr, heading « les avis et rapports du Haut Comité ».

[65] Recommendation n°5 appearing in the opinion issued by HCTISN on 12th July 2010.

The termination of these contracts also partly explains the drop in slightly enriched uranium exchanges. Between 2010 and 2011, Russian deliveries to Eurodif of slightly enriched uranium dropped significantly, from about 500 t to less than 100 t and exports to Russia fell from about 600 t in 2010 to 0 t in 2011.

The drop in slightly enriched uranium exports can also be explained by the gradual reduction in those from Eurodif to a number of its partners: 200 t less between 2010 and 2011 to the Lingen plant in Germany, regular reduction of 50 t per year since 2010 in the contract with the Westinghouse plant in Springfields, United Kingdom, cessation of deliveries to the United States between 2011 and 2012 (about 200 t).

Finally, this drop can be explained by the cessation of exchanges of materials between the Romans-sur-Isère site and Dessel in Belgium, as in 2011 Areva envisaged closing the Dessel site. The cessation of these exchanges accounts for more than 200 t of the drop observed between 2011 and 2012.

A reduction in exchanges between the Areva sites and the Urenco sites in the Netherlands and Germany should also be noted. Natural uranium exports from Comurhex to these sites have been falling gradually since 2012: down from about 2,000 t in 2012 to about 1,000 t in 2013 with the German Urenco site, and from about 3,000 t in 2013 to 0 t with the Dutch site. These contracts had gradually grown between 2008 and 2012, which explained a high level of natural uranium exports in 2010 and 2011 (about 8,300 t), before falling to a significantly lower level today.

This drop in natural uranium exports can be paralleled with the drop in returns of depleted uranium and slightly enriched uranium observed over the same period. The Eurodif depleted uranium delivery contracts with the Urenco site in Germany ended in 2013 (900 t less imports than in 2012) and the contracts between the Pierrelatte site (Eurodif closure and GB2 start-up during this period) and Urenco's German and Dutch sites dropped significantly between 2012 and 2013 (the total volume exchanged went from about 7,500 t to 4,500 t). These contracts explain the drop of nearly 4,000 t in uranium imports observable between 2012 and 2013.

With regard to slightly enriched uranium, the Eurodif contracts with the Urenco sites in the United Kingdom and the Netherlands ended in 2012, accounting for about 230 t of the drop in imports between 2011 and 2012.

Finally, an exceptional supply of highly enriched uranium (200 kg) to Cerca by the United States should be noted in 2012. The import traffic returned to its usual level in 2013.

Exports

Reusable material	Reference data		2012 and 2013 data		Data updated at end 2014	
	Years 2006-2011: total exports		Total exports in 2012 (in tons)	Total exports in 2013 (in tons)	Years 2006-2013: total exports	
	Total 2006-2011 (in tons)	Average annual traffic (in tons)			Total 2006-2013 (in tons)	Average annual traffic (in tons)
Depleted uranium	45 599	7 600	3 848	5 511	54 958	6870
Natural uranium	37 550	6 258	6 021	5 151	48 722	6 090
Slightly enriched uranium	10 437	1 740	726	420	11 583	1 448
Highly enriched uranium	2	0	0.1	0.1	2.2	0.3
Plutonium	12	2	1.2	4.2	17.4	2.2
Thorium	16	3	1.8	1.8	19.6	2.5

Imports

Reusable material	Reference data		2012 and 2013 data		Data updated at end 2014	
	Years 2006-2011: total imports		Total imports in 2012 (in tons)	Total imports in 2013 (in tons)	Years 2006-2013: total imports	
	Total 2006-2011 (in tons)	Average annual traffic (in tons)			Total 2006-2013 (in tons)	Average annual traffic (in tons)
Depleted uranium	31 719	5 287	8 631	4 725	45 075	5 634
Natural uranium	63 934	10 656	11 559	9 969	85 462	10 683
Slightly enriched uranium	10 329	1 722	1 201	1 130	12 660	1 583
Highly enriched uranium	0	0	0.2	ns[66]	0.2	ns
Plutonium	2	0.3	0.3	0.4	2.7	0.3
Thorium	0	0	0	0	0	0

Table of direct exports and imports with all countries concerned by the nuclear industry (sources: HCTISN report on fuel cycle transparency and data transmitted annually by the DGEC to the HCTISN to update this report)

2.1.3 Method for assessing the reusability of materials

As specified in section 1.1.1, Article L. 542-1-1 of the Environment Code stipulates that a radioactive material is a radioactive substance for which further use is planned or envisaged, if necessary after processing.

However, to ensure safe and responsible management of radioactive waste and avoid radioactive substances from being incorrectly considered to be radioactive materials, with the risk of future generations having to bear the burden for their management, criteria are required for assessing the actual reusability of the radioactive materials held on French soil.

The following are therefore considered:

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[66] ns = not significant

- the use of the radioactive materials may be immediate or deferred, but must in any case be based on reasonably probable hypotheses;
- potential uses outside France may be considered, but account must then also be taken of all similar substances available on the world market;
- the reasonably reusable nature of a radioactive substance depends not only on the technical maturity of its reutilisation process, but also on foreseeable economic conditions, the socio-political conditions of its implementation and the balance between the quantity held, its rate of production and the anticipated consumption rates;
- the conditions for reuse of a radioactive substance may differ according to its content, chemical form, isotopes or association with other substances, and characteristic batches with homogeneous reutilisation conditions should be defined when there are possible differences between the various forms to be dealt with;
- the assessment of the actual reusability of a radioactive substance must take account of any incompatibilities with the envisaged method of reutilising other radioactive substances.

The status of radioactive material thus depends primarily on the technically reusable nature of the substance, but also on the industrial strategy of the owner and on energy policy (French in particular) for its actual reutilisation. The reutilisation conditions for radioactive materials need to be periodically reviewed, more specifically to keep pace with changes in energy policy or technical advances.

Article L. 542-13-2 of the Environment Code states that after obtaining the opinion of ASN, the State may reclassify radioactive materials as radioactive waste if the prospects for reusing these materials are not sufficiently well established. It can also cancel this reclassification in the same manner.

2.2 Management routes

For each type of radioactive material, this section details:
- the current methods for utilising radioactive materials held on French soil, with a summary of quantities stored and a survey of foreseeable needs such as to be able to meet stock growth prospects;
- the reutilisation prospects envisaged by those holding the radioactive materials, along with an assessment of the likelihood of these prospects being realised in the light of the criteria presented in section 2.1.3.

It also presents considerations concerning interactions between reutilisation routes.

The situation of radioactive materials held and the technical reutilisation possibilities can be summarised as follows:

Nature of materials	**Approximate quantities on French soil at end 2013[67] in tHM***	**Planned or envisaged uses**
Natural and enriched uranium	28 800	Industrial utilisation established for the fabrication of UOx and MOx fuels
Depleted uranium	290 000	Utilisation as-is established for the fabrication of MOx fuel Reuse by re-enrichment achieved, feasibility of use in generation IV fast-neutron reactors demonstrated on industrial scale
Recycled uranium from processed spent fuel	27 000	Industrial use established for URT from processed spent UOX fuels (recycled as URE fuel)
Uranium oxide based fuels (new, in use, pending processing)	17 040	Industrial use established for new UOx and URE fuels. Processing and industrial scale reuse established for spent UOx fuels. Feasibility of industrial scale processing of spent URE fuels demonstrated for recycling in generation IV fast-neutron reactors.
Mixed uranium and plutonium oxide based fuels (manufacturing scrap, new, in use, pending processing)	2 378	After use of the new fuel, industrial scale feasibility demonstrated for processing for recycling in generation IV reactors
Research reactor fuels (new, in use, pending processing)	75.4	After use of the new fuel, processing feasibility demonstrated for most of these fuels, but new facilities are necessary. Recycling is planned in the generation IV fast neutron reactors.
National defence fuels	156	After use of the new fuel, processing feasibility demonstrated for recycling of most of these fuels, but new facilities are necessary.
Plutonium	52	Industrial use established for plutonium from reprocessed spent UOx fuels (recycled as MOx fuel)
Thorium	8 500	Significant industrial experience with processing of thorium-bearing substances. Industrial development in progress for medical purposes. Utilisation envisaged for energy production by means of two options: (i) transition to a thorium cycle within dedicated reactors, or (ii) introduction into existing technology reactors, in addition to the uranium-plutonium cycle

*Reusable materials, associated quantities and reutilisation status - *tHM: ton equivalent heavy metal*

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[67] Data from the 2015 edition of the National Inventory of radioactive materials and waste.

2.2.1 Uranium (natural, depleted, enriched and reprocessed)

Natural, depleted, enriched uranium

Utilisation

Enriched uranium and depleted uranium are produced by the uranium enrichment plants, which produce two types of substances: on the one hand, uranium enriched with isotope 235 at a level generally between 3 and 5% and used for fuel fabrication and, on the other, depleted uranium with an isotope 235 content of about 0.2 to 0.3%.

About 1,000 t of enriched uranium are used each year as fuel to produce nuclear generated electricity in France. To produce this quantity of enriched uranium, about 7,000 t of natural uranium are needed, which generates about 6,000 t of depleted uranium. To this annual traffic can be added about 1,500 t of depleted uranium produced for uranium enrichment on behalf of customers from other countries. In practice, the enricher becomes the owner of the depleted uranium. Areva thus takes possession of the depleted uranium resulting from the uranium it enriches, whether uranium from EDF or from a foreign customer (American, German, Korean, etc.).

Inventory of storage sites

Depleted uranium is stored on the Tricastin and Bessines-sur-Gartempe sites in the form of oxide, packaged in containers. At present, 5 buildings are in service on the Tricastin site and 9 on the Bessines site. These facilities are covered by the ICPE system and financial guarantees are required to ensure monitoring of the sites, keeping the facilities safe and response measures in the event of an accident[68].

The Areva storage concept is modular: capacity extensions by commissioning new buildings are technically possible. According to Areva, current capacity should not become saturated before 2022. These extensions require authorisation by means of a procedure taking between 2 to 3 years. Once authorisation is received from the competent authorities, construction of an additional module (building) only takes a few months, according to Areva. A certain margin is however required to take account of any technical and administrative contingencies in the design, construction and authorisation process for this storage capacity.

R1 – AREVA must take the necessary steps to ensure the availability of new storage capacity for depleted uranium given the stock growth prospects, more specifically taking account of the time needed to examine the necessary administrative authorisation applications.

R2 – In the light of the available information regarding saturation of existing storage capacity, AREVA must submit an application to extend depleted uranium storage capacity no later than 31st December 2017.

I1 – Occupancy levels of depleted uranium storage facilities.

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[68] Order of 23rd June 2015 concerning facilities utilising radioactive substances, radioactive waste or solid residues from uranium, thorium or radium ore, subject to authorisation under section 1716, section 1735 and section 2797 of the nomenclature of Installation Classified on Environmental Protection Grounds.

Reutilisation prospects

The French stock of depleted uranium amounted to 290,000 t as at the end of 2013. Its annual growth as a result of production/consumption traffic is about 7,000 t but this could be reduced if one of the three main routes for reutilisation of this substance being envisaged by Areva were to be implemented.

For several years, depleted uranium has been regularly used as a basic product in uranium and plutonium oxide based fuel ("MOx" fuel) produced in the MELOX plant in Marcoule. This route however only consumes about a hundred tonnes per year.

Depending on the price of natural uranium, depleted uranium can also be re-enriched to take its place[69]. The 290,000 t of depleted uranium held as at the end of 2013 could – if re-enriched – give a stock equivalent to about 50,000 t of natural uranium[70]. The forecast price trends presented by Areva, established on the basis of an assumption of a 50% rise in world nuclear energy production in 2030 by comparison with 2013, anticipates re-enrichment being once again economically competitive in about 2020. This would however mean mainly producing uranium that is "more depleted", with an enrichment of 0.1 to 0.2%[71] and which, below a certain threshold (today estimated at about 0.1%), can no longer be reused in this route.

For the longer-term, the stocks of depleted uranium could be reused on a large scale in the generation IV fast neutron reactors, the deployment of which could be decided on in the second half of the century. This type of reactor could make full use of the energy potential of uranium isotope 238 (see section 2.3) and thus reutilise all or part of the French stock of depleted uranium. The studies submitted in compliance with the 2013-2015 PNGMDR show that the French stock would represent an equivalent of about 1,000 to 10,000 years of operation of a fleet of generation IV fast neutron reactors with a power of 60 GWe in a scenario involving the introduction of the first reactors in 2040, with a power ramp-up until 2100[72].

Other secondary avenues for reutilisation, already being implemented, such as manufacture of biological shielding, or to be investigated: applications using the density properties of uranium, use in batteries, etc., are also being envisaged, but given current knowledge they could not on their own reuse the entire French stock of depleted uranium.

In the light of these reutilisation prospects and processes, which are presented in greater detail in the study submitted by the depleted uranium owners pursuant to the 2013-2015 PNGMDR, ASN – in its opinion of 9th February 2016 – considers that the technical feasibility of using this substance is confirmed by operating experience feedback but that the part of the stock that cannot be reused in a thermal neutron reactor fleet should in the meantime be reclassified as waste and that the funds necessary for its long-term management should be ring-fenced.

Management options if depleted uranium were to be reclassified as waste

The current specific activity of depleted uranium is estimated by Areva at 40,000 Bq/gU, with a radiological peak (about 110,000 Bq/gU) which should be reached three million years after its

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[69] The economic conditions of 2007 and 2008 were favourable for such reutilisation on an industrial scale: 7,800 t of depleted uranium were thus used in France to obtain the equivalent of 1,800 t of natural uranium.

[70] By comparison, the "gross" world demand expressed in equivalent natural uranium was about 66,000 tU in 2014.

[71] New technologies such as laser enrichment, could eventually lead to greater separation, reaching levels of below 0.1%, thus slightly improving the efficiency of the operation.

[72] Each year of postponement beyond the 2040 milestone for the commissioning of the first generation IV reactor leads to these durations between extended by 20 to 160 years.

production. These characteristics, more particularly the uranium activity after 300 years, means that disposal in the existing facilities cannot be envisaged.

A study carried out by Areva for the purposes of the 2010-2012 PNGMDR concluded that the sufficient characteristics of the geological medium for the disposal of depleted uranium were on the whole similar to those being sought for the disposal of LLW-LL waste. In accordance with the 2013-2015 PNGMDR, Areva is required to look further into this subject, by providing evaluations of the radiological and chemical impact for normal or altered evolution scenarios, in accordance with the safety guidelines set down by ASN.

R3 – In order to assess the consequences of possible reclassification of all or part of the stocks of depleted uranium as radioactive waste and building on the knowledge acquired during the ongoing disposal project studies, Andra shall before the end of 2019 produce a feasibility study for a disposal concept, indicating the associated costs, on the basis of a detailed radiological and chemical inventory of these substances transmitted by the parties in possession thereof. Andra will also present the potential impact of these quantities of waste on the planned disposal routes.

Reprocessed Uranium

Utilisation

Reprocessed uranium, also called recycled processed uranium (URT), is extracted from uranium oxide based spent fuels, of which it constitutes about 95% of the mass. The URT present on French soil is mainly owned by EDF, Areva and, to a lesser extent, CEA. Its energy value in the reactors operated by EDF when re-enriched is comparable to that of enriched natural uranium.

The URT is recovered from the processing-recycling plants in the form of uranyl nitrate. It is oxidised and stored in the form of U_3O_8 in the facilities on the Areva NC site in Tricastin pending its reutilisation. Whether or not reutilisation is opportune depends mainly on the economic attractiveness of the URT by comparison with natural uranium, its role in the security of supply and the existence of facilities enabling it to be used.

This reprocessed uranium can be sent to an enrichment plant to produce enriched recycled uranium (URE) used for fabrication in the Areva NP plant in Romans-sur-Isère of nuclear fuels intended for light water reactors. From 1994 to 2013, of the 1,000 t of URT produced each year in the La Hague plants, from 300 to 600 t were re-enriched annually and supplied to the four reactors at Cruas in place of natural uranium.

Until now, the French URT has been re-enriched abroad (Russia and Netherlands) because the technology employed in the George Besse I plant was unable to do so: it was dedicated exclusively to the enrichment of natural uranium. The Georges Besse II plant, which has replaced it, uses a different isotope enrichment technology (ultra-centrifuge) and, subject to ASN approval, is authorised to enrich URT in one of the North unit's modules. Areva indicates that in the light of the industrial needs expressed by its customers, it has no plans to make such an application in the coming years, but that it would do so if the industrial need were to be confirmed.

Inventory of storage sites

As at the end of 2013, about 27,000 t of URT were packaged in drums and stored, mainly in specific areas on the Tricastin site. An increase of about an average of 1,150 t/year in the quantities stored is anticipated over the next fifteen years. Given the volume of the drums, their arrangement and the stacking conditions, the physical saturation of storage capacity in terms of volume will be reached before saturation in terms of tonnage (authorised uranium tonnage limit for these areas).

The stock currently stored corresponds to an overall physical occupancy (in equivalent drums) of about 80% of the total physical capacity available in the storage areas dedicated to URT. According to Areva, the current storage areas are sufficient for storage of reprocessed uranium until 2021 and the definition of additional reprocessed uranium storage capacity beyond 2021 depends on the industrial choices made with respect to the uranium recycling solution. However, again depending on these same industrial choices, additional storage capacity could be needed to ensure storage of reprocessed uranium beyond 2021.

Given the potential saturation of existing storage capacity by 2021 at the earliest and given the programmes for possible removal of URT from storage by EDF, for reuse in the fuel cycle, the design and construction times, the authorisation examination times and the technical or legal contingencies, a total of 5 years should be considered for the commissioning of new reprocessed uranium storage capacity

R4 – The URT owners must take the necessary steps to ensure the availability of new storage capacity for reprocessed uranium given the stock growth prospects, more specifically taking account of the time needed to examine the necessary administrative authorisation applications.

R5 – In the light of the available information regarding saturation of existing storage capacity, AREVA must therefore submit an application to create or extend reprocessed uranium storage capacity to the competent administrative authority no later than 31st December 2017.

I2 – Occupancy levels of URT storage facilities.

Reutilisation prospects

Using up the stock of URT, which should reach 34,000 t as at the end of 2020, is technically possible by manufacturing fuels based on this uranium (URE) which could then be consumed in all or some of the existing or future reactors, in the same way as the recycling that was carried out in Cruas until 2013. Future reutilisation of this stock depends on the economic context (difference between the cost of the URT technology and that of the natural uranium solution), the security of supply issues and the authorisations that could be issued by ASN for operation of the reactors with URT fuel[73]. ASN has not been informed by EDF that any application for authorisation to run reactors other than Cruas with URT would be made in the next few years.

EDF considers that in the light of the economic prospects, the resumption of this reutilisation route could be envisaged in about 2020, with corresponding consumption of about 600 t/year,

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[73] EDF considers that the URT could be consumed in its NPPs other than Cruas, given that no technical obstacle has so far been identified. This utilisation would nonetheless compete with that of MOx if the URT were intended to be used in the reactors authorised to use MOx.

which would enable 6,000 t to be consumed every 10-year period. By this time-frame the changing supply-demand balance for natural uranium could in fact create an economic context that is more favourable to URT recycling, in France and internationally.

There is also significant experience of URT recycling worldwide: 75 reactors have been loaded with URT (mainly in Western Europe, Russia and Japan) and this is more particularly developing in countries with both light water and heavy water reactors, such as South Korea, India and China. Countries such as Argentina and Romania are also taking an interest in the use of URT for their fleet of CANDU[74] reactors.

In the longer term, URT could also be used in the generation IV fast neutron reactors.

The presentation of available URT stocks in the form of homogeneous batches would make it possible to consolidate the reutilisation prospects for batches consisting of actually mobilisable URT physico-chemical forms.

R6 – The URT owner must present the stock of URT consisting of various homogeneous batches, for example by differentiating between URT from industrial processing of UOx fuels and that consisting in full or in part of materials from (sometimes isolated) campaigns to reprocess GCR, MOx and URE fuels.

As a result of the significant stock of URT today held in France, the PNGMDR requests a strategy for eventually capping the stock held, consistently with the envisaged reutilisation prospects. In its opinion of 9th February 2016, ASN considers that it is also necessary to specify the conditions for the reutilisation of reprocessed uranium and to ensure that this stock is capped in the medium term.

R7 – Before 31st December 2017, the URT owners must present a strategy for a medium-term reduction in growth of URT stocks held and then to ensure that these stocks are capped. The key steps and corresponding deadlines for monitoring this strategy must be identified.

Management options if URT were to be reclassified as waste

A study conducted by EDF and AREVA within the framework of the 2010-2012 PNGMDR concluded that near-surface disposal could be a management method for URT, if this material were to become considered as waste. In accordance with the 2013-2015 PNGMDR, EDF and Areva are required to look further into this subject, by providing evaluations of the radiological and chemical impact for normal or altered evolution scenarios, in accordance with the safety guidelines set down by ASN.

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[74] In 2014, the worldwide consumption by the CANDU reactors was about 3,000 tons of natural uranium per year.

R8 – In order to assess the consequences of possible reclassification of all or part of the stocks of URT as radioactive waste and building on the knowledge acquired during the ongoing disposal project studies, Andra shall before the end of 2019 produce a feasibility study for a disposal concept, indicating the associated costs, on the basis of a detailed radiological and chemical inventory of these substances transmitted by the parties in possession thereof. Andra will also present the potential impact of these quantities of waste on the planned disposal routes.

2.2.2 Uranium oxide based fuels (UOx and URE)

Current management modes

After unloading, uranium oxide based spent fuels are stored in the spent fuel pools in the fuel buildings (BK) of the nuclear power reactors. After a cooling period of about 1 to 2 years, long enough to enable them to be transported, they are taken from the production sites to the La Hague plant, where they are again stored in pools. The average time lapse between unloading and processing is about ten to fifteen years.

Reutilisation of spent fuels from nuclear power reactors has been used for several decades on an industrial scale for enriched natural uranium based UOx fuels consisting of uranium dioxide pellets. In accordance with the traffic balancing principle applied by EDF, the annual processing traffic is calculated so as to obtain no more than the precise quantity of plutonium necessary for fabrication of the MOx fuel. This principle helps control the quantity and quality of the plutonium stock.

In its opinion of 20th July 2016 on the 2016-2018 PNGMDR, the environmental authority recommends a comparative assessment of the impacts on the population and the environment of the various possible or envisaged alternatives for management of radioactive materials and waste, in particular the processing of spent fuels.

R9 – Together with EDF, CEA and Andra, Areva will before 30th June 2018 carry out a comparative analysis of the environmental impacts of a spent fuels processing strategy, as compared with a strategy with no processing, giving consideration to the entire fuel cycle, from uranium mining up to the disposal of the secondary waste.

Inventory of storage sites

The total spent fuel storage capacity in BK[75] spent fuel pools is 8,100 tHMi. More specifically for NPP routine operations reasons, some of this capacity is at present allocated to uses other than storage of spent fuel alone. At the end of 2013, the available capacity actually allocated to spent fuels was 5360 tHMi, or an occupancy ratio of about 80%.

The total authorised capacity of the La Hague pools is 17,600 tHMi. This capacity is used to store not only the uranium oxide based fuels, but also those based on mixed uranium and plutonium oxides. It is not however exclusively allocated to the storage of French cycle spent fuels.

EDF considers that the available capacity will enable spent fuels to be stored for at least the next 10 years. EDF is studying new capacity options before saturation of the existing capacity which, depending on the scenarios envisaged, will not happen before 2030 at the earliest. At this stage in the study, considering that the design/construction of a new storage facility requires about 15 years, EDF envisages submitting a creation authorisation decree (DAC) application before the end of 2020. Given the envisaged time-frame for saturation of spent fuel storage capacity and given the time necessary for the design and construction of such a facility, ASN drew "*the attention [of EDF] to the eventual saturation of French spent fuel storage capacity*" and asked EDF *"in the next update of the file to present its strategy on this subject and the various contingencies associated with the creation of new storage capacity"*. In the light of the information at its disposal, ASN stated that *"transmission of a safety options file (DOS) by EDF within a period of 12 to 18 months is necessary"* in order to create such capacity.

Stocks of uranium-based spent fuel assemblies (ACU) in spent fuel pools as at end of 2013			
	EDF BK	La Hague	total
Spent UNE fuels	3 700 t_{HMi}	8 230 t_{HMi}	11 930 t_{HMi}
Spent URE fuels	110 t_{HMi}	310 t_{HMi}	420 t_{HMi}
Total	**3 810 t_{HMi}**	**8 540 t_{HMi}**	**12 350 t_{HMi}**

R10 – Given the prospect of saturation of spent fuel storage capacity (spent UOx, URE, MOx fuels) between 2025 and 2035, EDF must:

- **No later than 31st March 2017, present its strategy for managing PWR spent fuels storage capacity (UOx, URE and MOx spent fuels) and the corresponding calendar for the creation of new storage capacity (extension of an existing facility or creation of a new one);**
- **No later than 30th June 2017, send ASN the technical and safety options for the creation of new storage capacity (extension of an existing facility or creation of a new spent fuel storage facility);**
- **Before 31st December 2020, submit a creation authorisation application to the Minister responsible for nuclear safety, for the creation of a new spent fuels storage facility (or an application for a substantial modification if extending an existing facility).**

I3 – Occupancy levels of spent fuel storage facilities in the La Hague plants.

I4 – Occupancy levels of spent fuel storage facilities in the EDF NPPs (BK spent fuel pools).

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[75] This capacity corresponds to the total capacity of the BK pools after deduction of the space needed to unload the complete cores of the corresponding reactors.

Reutilisation prospects

Spent fuels based on re-enriched processed uranium (URE) are not reprocessed. With regard to the uranium in the spent URE fuels, its ^{232}U content is generally higher than that of the reprocessed uranium from UOx fuels, making its recycling in light water reactors less attractive, as the 232 isotope is prejudicial to the fission reaction. The same applies to the plutonium from spent URE fuels as compared with UOx, again with isotope levels less favourable to the fission reaction. Whether for uranium or for plutonium, these limitations are linked to the neutronics of current light water reactors. Their processing and recycling could however produce feedstock more specifically for the deployment of a fleet of generation IV fast neutron reactors. With this in mind, spent URE fuels are currently being stored.

Management options if UOx and URE fuels were to be reclassified as waste

It the UOx and URE spent fuels were at some time to be reclassified as waste, they would require specific packaging for direct deep geological disposal. Pursuant to Article L. 594-1 and following of the Environment Code, EDF is required to make provision for the downstream costs of managing irradiated UOx fuel based on enriched natural uranium[76]: transport, spent fuel pool storage, processing-oxidation, storage and management of the cycle waste. For spent URE fuel, provision is made for its storage and direct disposal; the rules of accounting prudence mean that given the lack of certainty as to the construction of a fleet of generation IV fast neutron reactors, the solution adopted when calculating these provisions is that of direct disposal of URE fuels, without processing. The studies concerning the possibility of direct disposal of spent fuels in a deep geological facility are described in detail in Chapter 4.1.

2.2.3 Mixed uranium and plutonium oxide based fuels (MOx, MOx scrap, SuperPhenix and Phenix)

Current management modes

As also specified in section 2.2.5, the plutonium produced by processing of spent UOx fuels is used to manufacture about 120 t/year of MOx fuels also containing depleted uranium oxide.

Non-irradiated MOx fuel scrap[77] are radioactive substances (pellets, powders, etc.) which are not directly recycled in the MELOX production circuit. These substances are for example packaged in cans, rods or assemblies and then shipped in dedicated packagings to La Hague for storage and then processing for future use of the separated materials. The quantity of uranium and plutonium oxide based fuel scrap present on the La Hague site as at the end of 2013 was about 234 t.

This stock will be reprocessed in existing or future facilities on the La Hague site, for use in current or future reactors. The entire inventory of scrap should eventually have been recycled by the end of the fleet lifetime.

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[76] An irradiated fuel is one that has been introduced into the reactor and irradiated.

[77] The distinction between MOx fuels and scrap was introduced by the order of 4th April 2014, amending the order of 9th October 2008 concerning the nature of the information that those responsible for nuclear activities as well as the companies mentioned in Article L. 1333-10 of the Public Health Code are required to produce, update and periodically transmit to the French National Agency for the Management of Radioactive Waste.

In its opinion of 9th February 2016, ASN considers that the owners of the various types of scrap held must submit clarification of the conditions and prospects for reutilisation of each type of MOx fuel scrap before the end of 2017.

Inventory of storage sites

Stocks of plutonium-based (MOx) spent fuel assemblies (ACU) in spent fuel pools (BK + La Hague) as at end of 2013			
	BK EDF	La Hague	Total
Spent PWR MOX fuels	340 t_{HMi}	1 200 t_{HMi}	1 540 t_{HMi}

Stocks of FNR MOx fuels as at end of 2013			
	APEC (Superphenix))	La Hague + Marcoule (Phenix)	Total
FNR MOX fuels	176 t_{HMi}	38 t_{HMi}	214 t_{HMi}

Reutilisation prospects

Given the isotopic characteristics of the plutonium contained and the quantities of spent MOx fuels unloaded from the French nuclear reactors, the industrial management of these fuels today preferred by EDF is recycling in the generation IV fast neutron reactors (FNR). With this in mind, the plutonium is currently being kept within the spent MOx fuels until needed.

The Astrid FNR-sodium technology demonstrator (see section 2.3) which is planned, could be partly fed with plutonium from processing of Phenix fuels. To do this, a special fuel processing facility (TCP project) is currently being designed and at the end of 2015, Areva sent ASN a safety options file for this unit. This facility would be located on the La Hague site and should be the subject of an authorisation procedure as and when necessary.

The industrial scenario studies jointly performed by CEA, EDF and Areva, concerning the gradual phasing-in of fast neutron reactors, show that a small number of reactors would be able to recycle all the plutonium from spent MOx fuels. The feasibility of this reutilisation in fast neutron reactors implies industrial proficiency in the processing of spent MOx fuels, the industrial feasibility of which has been established on a small scale[78]. Systematic recycling of the plutonium from all spent fuels, including that of spent FNR fuels, would however require the deployment of a significant fleet of FNR reactors well beyond the few units needed simply to recycle the MOx fuels from the light water reactors.

Alternative management solutions for the plutonium from spent MOx fuels have been evaluated, for example by mixing with enriched uranium (MIX fuels), or mixing with the plutonium from spent UOx fuels. The studies have not demonstrated any clear advantage of these alternative management solutions over the current and envisaged management modes.

The future management strategy for the plutonium contained in the Superphenix reactor fuels - a new core and an irradiated core stored in the APEC[79] facility - has not yet been determined. Its isotopic characteristics mean that it is technically possible to use it to manufacture new MOx fuels.

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[78] About 70 tons of spent MOx fuels from pressurised water reactors have already been reprocessed in the La Hague plant. In addition, several tens of tons of spent MOx fuels from fast neutron reactors (FNR) have been reprocessed at La Hague and in Marcoule.

[79] The APEC (fuel storage facility) more particularly comprises a wet storage building (pool) and a dry storage building. The spent fuel assemblies unloaded from the core of the Superphenix reactor are stored in the pool, as are the new fuel assemblies.

R11 – The radioactive material classification of spent MOx and URE fuels must be periodically reassessed.

R12 – The owners of spent URE and MOx fuels must therefore:
- **declare the technical-economic feasibility of large-scale processing of these fuels and then calculate the substances separated (uranium and plutonium) in the cycle facilities and in the thermal neutron reactors;**
- **specify the quantities of plutonium needed for the deployment of a fleet of generation IV fast neutron reactors and, as necessary, specify the maximum quantities of spent URE, MOx and UOx fuels not used in the current fleet which could be mobilised for this purpose.**

This information must be communicated before 31st December 2017.

Management options if the spent MOx fuel were to be reclassified as waste

An energy policy which decided not to opt for complete recycling of all spent fuels would in the end mean disposal of the spent MOx fuels, which would then have to be dealt with in a nuclear waste deep disposal repository as presented in Chapter 4.2 of the PNGMDR. With this in mind, EDF is setting up provisions for the funds needed for disposal of these fuels, in compliance with the studies and updated cost estimates[80].

2.2.4 Fuels from research and naval propulsion reactors

Annual traffic, management modes and inventory of research fuel storage facilities

Fuel consumption for research purposes is primarily by the two main French research reactors, OSIRIS and ORPHEE. OSIRIS was finally shut down at the end of 2015 (until which time its fuel consumption was about 0.15 t/year) and CEA intends to finally shut down ORPHEE at the end of 2019 with anticipated consumption until shutdown of 0.015 t/year. It is also expected that the RHF reactor operated by ILL will consume about 0.050 t/year until the 2030-2032 time-frame. The future RJH reactor should consume about 0.150 t/year once it is commissioned, scheduled for 2021.

With regard to storage capacity, CEA has the CASCAD facility on the Cadarache site, for storage of fuels in a dry pit. This facility comprises 315 storage pits. As at the end of 2014, this facility had an available capacity of 37 pits (or about 16 tHMi) for storage of civil fuels removed from storage in various other CEA facilities. CEA stated that this available capacity is adequate to meet its programme forecasts for the coming decade.

As at the end of 2013, the quantities of spent fuels from research reactors stored in La Hague[81] stood at 3.8 tHMi. These quantities should not exceed about 5 tHMi in the coming 15 years.

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[80] The same applies to the spent URE fuel presented in section 2.2.1.

[81] The total administrative capacity of the La Hague pools is 17,600 tHM.

Reutilisation prospects

Fuels from research reactors (57 t of spent oxide fuels and 19 t of spent metal fuels) are, according to their owners, entirely[82] intended for processing and the materials they contain (uranium and plutonium) for recycling. To do this, a special technique is used in the La Hague plant to reprocess the fuels from certain reactors today shutdown, decommissioned and delicenced, or undergoing decommissioning (RUS in Strasbourg and CEA's SILOE, SILOETTE, ULYSSE and SCARABEE reactors).

Areva's operational nuclear fuel processing facilities at La Hague are authorised to reprocess certain fuels from research reactors, including those highly enriched in isotope 235. Areva has experience feedback from operations and processing of research reactor fuels carried out in the Marcoule and La Hague plants.

The "caramel" type fuels (sandwich of enriched uranium alloy between two metal plates) used in other research reactors (OSIRIS, ISIS, ORPHEE) are intended for processing, even if no industrial processing campaign[83] has yet taken place in the La Hague plants and this processing is not as yet authorised in these plants.

According to CEA, the reference solution for the small quantities of spent research fuels of other types (legacy metal fuels and experimental rods and samples), at present stored on the CEA sites, is future recycling. From the technical viewpoint, these fuels are comparable to "caramel" fuels, for which industrial processing will require new equipment in the La Hague plants.

The very small quantities of waste (vitrified or technological waste containers) that will result from recycling of the above-mentioned spent fuels are counted in the design-basis inventory of the Cigeo deep geological disposal project.

The 156 t of spent fuels from nuclear propulsion contain materials of interest for Defence for which processing is planned after a period of storage. The ultimate waste that will result from this recycling is counted in the design-basis inventory of the Cigeo deep geological disposal project. From the technical standpoint, the spent fuels from naval propulsion are comparable to "caramel" fuels, the industrial processing of which will require new equipment in the La Hague plant.

R13 – Each owner of spent fuels from research reactors must give a detailed presentation by the end of 2017 of the types of all the spent fuels in its possession, the developments required to enable them to be reused and the benefits of the properties of the separated materials with a view to reutilisation. Together with Andra and Areva, the owners will also communicate the detailed assessment of the cost of a processing programme for these spent fuels by comparison with direct disposal.

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[82] By comparison with the 2013-2015 PNGMDR, EDF now considers the spent fuels from the EL4 reactor in Brennilis (about 27 m^3) to be radioactive material.

[83] To date, only "caramel" type fuels from the OSIRIS research reactor have been processed by CEA Marcoule as part of the post-operational clean-out process: 2.3 tons of UO_2 have been processed, to validate the concept. Nonetheless, the industrial feasibility of reprocessing in the La Hague plants has not as yet been demonstrated.

2.2.5 Plutonium

In the same way as uranium, the plutonium contained in spent fuel assemblies is extracted during processing. A uranium spent fuel irradiated in a PWR today contains about 1% of plutonium by mass. Once dissolved, extracted and separated from the other materials contained in the spent fuel, the plutonium is purified and packaged at Areva La Hague in a stable PuO_2 oxide powder form. Plutonium is at present reutilised in MOx fuel. This fuel consists of pellets of $(UPu)O_2$ oxide powder produced from depleted uranium acting as the support, plus plutonium.

In France, 24 reactors are authorised to load MOx fuel and nearly 10% of nuclear generated electricity is today produced using this fuel. The plutonium requirements for fabrication of MOx fuel, standing at about 10 tons per year, determines the annual traffic of EDF spent fuels processed in the La Hague plant by Areva, with the goal of keeping the separated plutonium inventory stable.

In the longer term, the plutonium could also be used in the generation IV fast neutron reactors.

As at 31st December 2013, just over 52 tons of plutonium were stored in France:
- 41 tons of plutonium stored at the Areva plant in La Hague, 16 tons of which belongs to customers from other countries;
- 9 tons of plutonium currently in use in the process to manufacture MOx fuels (in the form of PuO_2, mixed oxide $(UPu)O_2$ or finished MOx assemblies), 1 ton of which belongs to customers from other countries;
- about 2 tons of plutonium stored in various CEA facilities.

There is no reason for this inventory to grow, because according to Areva:
- the existing foreign part, which is mainly Japanese, will continue to shrink, in particular with the probable restart of the Japanese nuclear reactors and confirmation of the continuation of the “Pluthermal” programme (“moxification” programme for the Japanese NPPs);
- the French processing-recycling policy is based on the principle of a balanced plutonium traffic, with the level of processing being adjusted to the recycling capacity of this material in the reactors using MOx fuel. The stock of plutonium needed to produce about 120 t/year of MOx fuel may vary from one year to the next, but on the whole remains stable and meets operational flexibility requirements.

The physical occupancy of the plutonium storage facilities at La Hague remains at about 2/3 of available capacity. In its opinion of 9th February, ASN considers that, in the light of the data presented (25 tons stored at La Hague, excluding customers from other countries) and within the framework of the 2013-2015 PNGMDR studies, Areva must before the end of 2017 demonstrate that the stock of plutonium in its possession is optimised with respect to the envisaged reutilisation modes.

Concerning the plutonium held by CEA, it aims to be able to use it in future fuel and reactor study and research programmes, in particular those concerning generation IV fast neutron technology, as well as in MOx fuel technology. This comes in a variety of physico-chemical and isotopic forms and it will be necessary to ensure that they can be effectively reused.

The entire stock of plutonium from spent fuel processing should in the end be recycled in some form of fuel.

R14 – Before the end of 2017, CEA must provide additional substantiation of the effectively reusable nature of all physical-chemical and isotopic forms of the plutonium it holds. It will specify the developments required to enable it to be reutilised.

2.2.6 Thorium

Solvay and Areva are in possession of about 8,500 tons of thorium, in nitrate and hydroxide form. These substances are stored on the sites at La Rochelle (about 6,200 t) and Cadarache (about 2,300 tons).
Areva's drums of thorium nitrate are stored in CEA's MMB facility in Cadarache. Between 2005 and 2012, these drums were placed in stainless steel over-drums and stored for a period of more than 50 years, on metal pallets.
Solvay stores its thorium-bearing substances on the La Rochelle site. The envisaged processing of the 21,700 t of hydroxides will entail their replacement by about 4,500 t of thorium nitrates packaged in stainless steel drums. Solvay therefore foresees no additional demand for thorium-bearing substances storage capacity.

The storage facilities for these thorium-bearing substances fall under the ICPE system and financial guarantees are required for monitoring of the sites, maintaining the facilities in a safe state, along with any necessary response measures in the event of an accident[84].

Reutilisation prospects

Thorium has no established use on an industrial scale today, but Areva and Solvay anticipate considerable potential[85], justifying the classification of the stored thorium-bearing substances as radioactive materials.

By neutron capture, thorium 232 can transmute into fissile uranium 233. A "thorium cycle", using thorium as a fuel and based on recycling of thorium and uranium 233 without using uranium 235 or plutonium, could therefore possibly be envisaged. Several decades would however be needed to see this avenue to fruition, given the research and development work still to be completed[86].

According to Areva and Solvay, a gradual introduction of thorium into the reactors, in order to improve the uranium-plutonium cycle, allowing multi-recycling of these fissile materials, could however be conceivable in the shorter term, depending on needs and on how the natural uranium market develops. They have thus initiated a multi-phase R&D programme on applications in the reactor. The first phase aiming to identify the potential uses of thorium in a light water reactor and then to identify the available technologies, the possible partnerships and the applied R&D programme to be implemented, was finalised in 2012. Preliminary characterisation tests on thorium powder were carried out in 2014. The research programme, established up until 2018, includes tests on fuel behaviour under irradiation, experiments on fabrication and processing, and analysis of the thorium fuel deployment scenarios, with the goal of obtaining qualified fuels by the 2030 time-

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[84] Order of 23rd June 2015 concerning facilities utilising radioactive substances, radioactive waste or solid residues from uranium, thorium or radium ore, subject to authorisation under section 1716, section 1735 and section 2797 of the nomenclature of classified installations.

[85] See joint EDF/CEA/AREVA/Solvay report submitted pursuant to the 2013-2015 PNGMDR.

[86] See report from the Nuclear Energy Agency: Introduction of Thorium in the Nuclear Fuel Cycle, OECD 2015 available on the web: https://www.oecd-nea.org/science/pubs/2015/7224-thorium.pdf

frame. Programmes to develop solutions to reutilise thorium in reactors are also under way in India and China.

At the same time, AREVA is continuing with its R&D activities to produce anti-cancer treatments by alpha radioimmunotherapy using lead 212 (decay element of thorium) which can be extracted from the thorium nitrates in a pre-industrial pilot or in the Maurice Tubiana Laboratory, both located in Bessines-sur-Gartempe. Clinical and pre-clinical trials have been started in the United States and France respectively. The possibilities for using lead 212 for this purpose however remain dependent on the demonstration of its clinical value, which would only be possible once the results of future clinical trials are obtained. In addition, even if the development of such applications were to justify the mobilisation of a large quantity of thorium, it is unable to ensure the long-term management of the thorium, be it technically, by studying its disposal, or financially, through the implementation of guarantees. Nor does the use of lead 212 modify the quantities of thorium-bearing substances held[87] and their radiotoxicity.

In the light of these prospects and reutilisation processes, which are presented in greater detail in the study submitted by the thorium owners within the framework of the 2013-2015 PNGMDR, ASN considers – in its opinion of 9th February 2016 – that ring-fencing of the financing of long-term management of the thorium-bearing substances is essential.

Management options if thorium-bearing substances were to be reclassified as waste

Within the framework of the 2010-2012 PNGMDR, and as a conservative measure, Areva and Solvay examined the modes of long-term management of thorium-bearing substances if thorium were one day to be reclassified as radioactive waste.

The radiological characteristics[88] of the stored substances: thorium nitrates, thorium hydroxides, ^{238}U in low proportions, etc. make them incompatible with surface disposal. On the basis of a study carried out by Andra, Areva and Rhodia adopted the disposal of radium-bearing waste as the reference concept. The calculations showed that the thorium and uranium concentrations in the environment, in normal conditions, would remain below 1 microgram per litre.

Areva and Rhodia conclude that a near-surface disposal facility accepting "radium-bearing" type waste would be a possible method of management for thorium-bearing substances, if thorium were one day to be considered as waste. Pursuant to the 2013-2015 PNGMDR, Andra, Areva and Solvay are required to submit a supplementary study[89] on the disposal of these substances more specifically to clarify: the radiological and chemical inventories of the substances concerned, the processing or packaging envisaged prior to disposal and the conceivable disposal concepts as related to the planned disposal facilities.

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[87] About 90 ng of lead 212 can be extracted per ton of thorium nitrates; this quantity is regenerated by radioactive decay after about ten years.

[88] The specific activities of the thorium nitrate and thorium hydroxide are about 5,000 Bq/g and 2,000 Bq/g respectively.

[89] Decree of 7th November 2014 implementing decree 2013-1304 of 27th December 2013 implementing Article L. 542-1-2 of the Environment Code and establishing the prescriptions of the National Plan for Radioactive Materials and Waste Management

Project for optimisation of the stock held through reutilisation of certain substances (rare earths, uranium)

A technico-economic optimisation project for management of all thorium-bearing substances (thorium hydroxides and nitrates, non-specific solid residues, suspended solids) stored on the La Rochelle site is being examined by Solvay. This project aims more particularly to reuse the uranium and rare earths present in thorium-bearing substances, to recover the thorium in a directly reusable form and to reduce the quantities of ultimate radium-bearing waste stored in appropriate conditions of safety, pending the opening of a disposal facility for LLW-LL waste.

The initial conclusions indicate that the main steps in the envisaged process have already been industrially utilised and that the technico-economic balance of processing, considered by Solvay to be interesting in the medium term, depends primarily on the date of opening of the disposal facility for the LLW-LL waste and its initial cost, as well as the sale price of rare earths and of thorium.

2.2.7 Other materials

Sealed sources

A significant share of used sealed sources, more particularly sources of Cobalt-60, Cesium-137 and americium-241[90], are recycled by the source manufacturers: they are then considered to be radioactive materials. Recycling these sources helps minimise ultimate waste, avoids saturating storage capacity and optimises costs.

There are different types of recycling process: addition of a capsule, replacement of the outer capsule, destruction of the capsules and physical processing of the radioactive material, destruction of the capsules and chemical processing of the radioactive material.

The recycling options depend more particularly on: the technical feasibility and corresponding cost, the cost of transportation, the technical capability of each manufacturer and the radioactive decay, which means that the remaining activity concentration of the recycled radioactive materials restricts their economic interest and ends up making them unusable in practice. The management modes for used sealed sources considered to be radioactive waste are presented in Chapter 4.3 of this PNGMDR.

Suspended solids (SS)

The Solvay radioactive materials stored in La Rochelle also comprise suspended solids (containing rare earth oxides and traces of thorium and uranium). The study submitted at the time by Rhodia concluded that reutilisation was technically and economically feasible. Recycling of these materials began in 2010 and should be completed before 2020.

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[90] Since 2010, in France, about 2000 TBq of Cobalt-60, 2000 TBq of Cesium-137 and a few tens of TBq of americium-241 have been returned to the manufacturers for recycling.

2.2.8 Potential future scenarios for the use of radioactive materials

In addition to the reference industrial scenarios, the 2015 edition of the National Inventory of radioactive materials and waste published by Andra gives an estimate of the production of radioactive waste and spent fuels according to two potential energy policy scenarios (continuation / non-renewal of nuclear generated electricity), the application of which influences the reutilisation possibilities for radioactive materials.

Within each scenario studied, the methods for reutilising a radioactive substance may be incompatible with those envisaged for other radioactive substances (for example, the "concurrent" use of processed uranium from UOx fuels in the form of URE fuels, or plutonium from spent UOx fuels in the form of MOx fuels). Greater attention must be given to this point in the forward-looking scenarios, in particular that for non-renewal of nuclear power generated electricity. The study of this scenario must identify a strategy for optimising consumption of the stock of spent fuels, plutonium and uranium held (in particular depleted uranium and URT) by giving priority in the fuel cycle to the use of substances for which disposal entails the greatest risks and drawbacks for protection of the interests mentioned in Article L. 593-1 of the Environment Code. The owners of radioactive materials will thus define a reutilisation strategy for the materials in their possession, taking account of all radioactive materials which could be reclassified as waste in such a scenario, as well as the principles of mitigation of the quantity and harmfulness of waste contained in the Environment Code.

R15 – The National Inventory comprises benchmark industrial scenarios and potential future scenarios. The potential future scenarios to be studied in the next edition of the National Inventory of radioactive materials and waste published by Andra shall more particularly take account of the following requests:

- **include benchmark industrial scenarios compatible with the objectives of the 17th August 2015 Act on Energy Transition for Green Growth;**
- **present a potential future scenario with discontinuation of nuclear generation of electricity, in which the materials not reutilised are reclassified as waste;**
- **study a variant of the scenario involving renewal of the NPP fleet, but in which the future fleet would not comprise fast neutron reactors.**

2.3 Work on generation IV fast neutron reactors

In addition to the structural parts of the assemblies which make up an ultimate waste, the spent nuclear fuel unloaded from the reactors after burn-up comprises about 95% residual uranium, 4% fission products (the fragments resulting from the fission of the ^{235}U and the ^{239}Pu) and 1% "transuranic" elements: essentially plutonium (for which most of the isotopes present are fissile), while the others, referred to as "minor actinides" because less abundant, only represent 0.1%.

The spent fuels processing-recycling strategy adopted by France more than 30 years ago, is in line with the principle defined by Article L. 542-1-2 of the Environment Code and allows the recycling in MOx fuels of the plutonium produced within the UOx fuels. Spent MOx fuels have also been reprocessed and recycled, but the physics of thermal neutrons rules out large-scale multi-recycling of plutonium and uranium in current pressurised water reactors. More extensive reutilisation of these materials, which would involve this type of recycling, constitutes a possibility in terms of the research being carried out into generation IV nuclear systems.

The fast neutron reactors (FNR) have a number of decisive advantages with regard to the management of materials as a complement to existing thermal neutron reactor technologies, which include the existing French PWR fleet. FNRs can thus make unlimited use of the plutonium produced by water reactors (or by themselves). They also enable all the natural uranium to be reused (all its isotopes, including isotope 238 which easily outweighs the others): which multiplies by a factor of nearly 100 the energy that can be extracted from a given mass of natural uranium. Once the stock needed for start-up has been created, they can also do without natural uranium[91]. The fast neutrons spectrum also opens up the possibility of transmuting certain minor actinides and could thus limit the footprint of the nuclear waste deep disposal site (see Chapter 4.3 on the partitioning and transmutation of minor actinides).

These prospects were partially confirmed in 2014 by the Advisory Committee for nuclear reactors, which informed ASN that: *"In the light of the report produced, the Advisory Committee considers that of the various nuclear systems envisaged by the GID [Generation IV Forum], only the SFR system [RNR-NA] is at present mature enough for the construction of a generation IV industrial reactor prototype to be conceivable in the first half of the 21st century. However, in the light of what was presented to it, the Advisory Committee cannot give any clear opinion, with regard to the industrial deployment of this technology, of the ability to achieve a level of safety significantly higher than that which is targeted for the EPR type pressurised water reactors, in particular owing to design differences and the current state of studies and research".*

On the basis of the lessons learned from previous reactors in France (Phenix in particular) and internationally, CEA, Areva and EDF set up an R&D programme in 2007, enabling design studies to be initiated for the Astrid FNR-sodium demonstrator in 2010. This demonstrator, with an electrical power of about 600 MWe, is primarily designed to provide a demonstration of the technological advances made, on a sufficient pre-industrial scale, while qualifying the innovative options during the course of its operation, in particular in the fields of safety and operability. Recommendation R8 of Part 4.2.3 of this PNGMDR specifies the expected objectives of the Astrid programme from the perspective of the Plan.

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[91] Whereas the French NPP fleet consumes about 7,000 tons of natural uranium every year and leaves behind about 6,000 tons of depleted uranium, a fleet of FNR of equivalent power would only require about 50 tons of depleted uranium each year. The stock of French depleted uranium as at the end of 2013 (about 290,000 t) would then be sufficient for the very long term.

3 Existing routes for radioactive waste management: summary and outlook

3.1 Management of legacy situations

Certain radioactive waste may in the past have been managed in ways that have since changed. This is particularly the case with disposal on or near to the production sites. This waste may also, in certain cases, have been used as backfill, or handled in routes defined specifically for the management of conventional waste. **The term legacy disposal sites is used to describe those places (except for mining processing residues and waste rock repositories) where radioactive waste not under Andra responsibility is placed and for which the producers or those in possession did not, at the time of placing it there, envisage management in existing or planned external routes dedicated to the management of radioactive waste.** This primarily concerns:

- thirteen conventional waste disposal facilities which had received VLL waste from the conventional or nuclear industries;
- waste disposed of close to or within civil or secret BNIs or defence-related nuclear experimentation sites and installations (SIENID);
- depots of waste with high natural levels of radioactivity (waste created by the transformation of raw materials naturally containing radionuclides but which are not used for their radioactive properties), which are not covered by the regulations for classified installations. This in particular concerns phosphogypsum waste from the production of fertilisers, residues from the production of alumina, coal ash from thermal power plants and residues from the production of rare earths from monazite.

The 2016-2018 PNGMDR requests completion of the investigations into the search for legacy disposal sites containing radioactive waste within or near the perimeters of nuclear installations and a substantiated presentation of disposal management strategies identified.

3.1.1 Context and issues

The management methods for radioactive waste have changed considerably.

- the immersion of low and intermediate level radioactive waste which France carried out in the Atlantic in 1967 and 1969, and then in the territorial waters of French Polynesia until 1982 is now a thing of the past and is prohibited by the regulations[92]. The inventory of immersed waste is given in Andra's national inventory[93] but is not dealt with in this chapter.
- the burial of residues from defence experiments or operating waste is now prohibited; these burial operations generally took place under a thick covering of conventional inert materials (concrete, rubble, soil) and both the disposal site and the environment are subject to specific monitoring;
- the disposal of certain very low level waste from civil BNIs or secret BNIs (SBNI) on or near the production sites or in conventional waste disposal sites, when the activity of the waste was felt to be low enough, has also ceased since the order of 31st December 1999[94] which comprises specific, reinforced provisions on the management of BNI waste. The general SBNI prescriptions also requested the application of this order before the official adoption of similar provisions in the order of 26th September 2007. The waste produced in nuclear installations has

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[92] Decree 2006-401 of 3rd April 2006 publishing the 1996 protocol to the 1972 Convention on the prevention of marine pollution from the dumping of waste and other matter, signed in London on 7th November 1996.

[93] The Inventory can be consulted on the Andra website L'Inventaire, http://www.andra.fr/, heading "Éditions".

[94] Order of 31st December 1999 amended, setting the general technical regulations intended to prevent and limit off-site detrimental effects and risks resulting from the operation of basic nuclear installations. This order was replaced on 1st July 2013 by the order of 7th February 2012 setting the general rules concerning basic nuclear installations.

since then been subject to specific, reinforced management. VLL waste in particular is disposed of in the industrial centre for collection, storage and disposal (Cires) in Morvilliers;
- waste with high natural levels of radioactivity from conventional industry were placed (disposal or transit) close to the production sites or in conventional waste disposal facilities subject to ICPE legislation, while some of it was reused (construction of buildings and roadworks), without the management methods appropriate to the nature of these waste being clearly implemented. They are now subject to specific management procedures presented in chapter 3.39, based on the requirements of the ministerial order of 25th May 2005 concerning professional activities involving raw materials naturally containing radionuclides not used for their radioactive properties.

The legacy waste disposal sites dealt with in this chapter correspond to the places (except for mining residues and waste rock disposal sites which are covered in Chapter 3.2) where radioactive waste not under Andra responsibility is disposed of and for which the producers or those in possession did not at the time envisage management in existing or planned external routes dedicated to the management of radioactive waste:

These concern:
- disposal in conventional waste disposal facilities which regularly or occasionally received waste with an added radioactivity of about a few Bq/g in many cases;
- waste repositories situated in or near a BNI, which may have regularly or occasionally received waste, most of which had an added radioactivity of about a few Bq/g;
- legacy deposits of waste with high natural levels of radioactivity[95] in facilities not subject to the regulations on classified installations.

In order to optimise the safe and responsible management of the legacy situations described above, the previous editions of the PNGMDR contained requirements that a process be initiated to identify and monitor legacy disposal sites and to define management strategies to be implemented or continued. The current state of knowledge, the monitoring actions being carried out and the management methods currently implemented for the identified disposal sites are presented in this chapter.

3.1.2 Legacy radioactive waste repositories in conventional waste disposal facilities

Very low level waste may have been disposed of in conventional waste disposal facilities. This primarily consists of sludges, earth, industrial residues, rubble and scrap metal from certain historical conventional industrial activities or from the civil or military nuclear industry.

The regulations ban the disposal of radioactive waste in non-hazardous waste disposal facilities, hazardous waste disposal facilities and inert waste disposal facilities since 1997, 1992 and 2004 respectively. These texts require a check on the waste prior to its acceptance, in addition to its characterisation, which is primarily the responsibility of the producer (Article L. 541-7-1 of the Environment Code). The checks performed at acceptance of the waste entail verification of the criteria set in the operating authorisation license. The hazardous waste disposal facilities and the non-hazardous waste disposal facilities must have the means of detecting radioactivity and implement specific waste management procedures if the alarm thresholds of the above-mentioned resources are exceeded.

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[95] Previously referred to as technologically enhanced naturally occurring radioactive materials (TENORM).

The national inventory of radioactive waste published in 2015 identifies thirteen conventional waste disposal facilities which have received radioactive waste. These facilities, shown on the following map, more particularly include the disposal facility in Vif (38) which received residues from the manufacturing processes in use in the Cézus plant, that in Menneville (62) in which phosphates transformation residues were disposed of, that in Pontailler-sur-Saône (21) and Monteux (84) which received waste from the purification sludges from the Valduc research centre and the manufacture of zirconium oxide respectively, and that in Solérieux (26) which contains fluorines from the Areva NC plant in Pierrelatte (ex-Comurhex).

Conventional waste disposal facilities which have received radioactive waste (Source: Andra)

Radiological checks were carried out on representative sites listed in the national inventory. Those which received the most radioactive waste, such as Solérieux or Vif, are placed under surveillance, in particular with radiological monitoring of the groundwater as part of the post-operational monitoring and surveillance process.

3.1.3 Legacy radioactive waste repositories within or close to a BNI or SBNI

The 2013-2015 PNGMDR asked the BNI and defence SBNI licensees (Areva, CEA and EDF) to continue the search for legacy disposal sites initiated under the previous version of the PNGMDR in order to verify that within the perimeter of these facilities or in zones historically used as annexes, there are no legacy disposal sites not declared to Andra for the inventory of radioactive materials and waste[96].

The investigation programme defined by the licensees for the 2010-2012 PNGMDR is based on:

- a survey of waste management documentation, historical investigations and (historical) environment monitoring;
- an analysis and audit step (interviews), possibly supplemented by in-situ measurements;
- definition of the management strategy if legacy waste repositories are discovered.

The licensees focused their searches on radioactive waste as defined in Article L. 542-1-1 of the Environment Code: *"waste containing radionuclides, the activity or concentration of which warrants radiation protection oversight"*. Although the waste zoning approach was only made mandatory with the order of 31st December 1999 (setting a deadline of 15th February 2001 for the definition of waste zoning), waste "liable to be contaminated or activated" were not in principle excluded from the framework of the investigations carried out, given the fact that the available data did not make it possible to determine the origin of the waste, nor obtain its radiological characteristics. All the waste disposed of is therefore considered first of all, with additional investigations then being carried out to determine the actual radioactive nature or otherwise of the waste considered. The licensees stated that, if in doubt, measurements to monitor the various compartments of the environment are taken and that if no radioactivity is detected, the waste is considered to be conventional. The licensees also stated that the complementary verification and control approach based on interviews with individuals who were not involved in the initial survey, could constitute a second, independent line of defence.

At the end of 2014, Areva, as well as EDF for sites being decommissioned and thirteen facilities in operation, continued to search for legacy waste repositories. The licensees stated that additional investigations were however still required in certain areas in which legacy repositories are suspected.

R1 – Legacy disposal sites discovered must be identified by the licensees regardless of their size and the recovery conditions envisaged or implemented. An update of the survey of legacy disposal sites must be made accordingly, incorporating the results of associated documentary and historical studies and measurements.

R2 – The investigations carried out by Areva, CEA and EDF must be completed by the end of 2017, more particularly for areas in which legacy disposal sites are suspected. The quality of these investigations shall be sufficient to enable the licensees to confirm that the survey of these disposal sites is exhaustive.

R3 – The physical and radiological inventory of the disposal sites discovered shall also be specified before the end of 2017, in particular in the Chooz A NPP for EDF.

Pending complete identification, the legacy disposal sites imply risks for construction work liable to take place on the site, which must be taken into account. In order to optimise the prevention of these risks in the future, conservation of a memory record is a point that needs to be reinforced.

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[96] The reports submitted by Areva, CEA and EDF are available on the websites of ASN and the Ministry responsible for energy:

- http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015 ;
- http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

R4 – Regardless of the prior investigations carried out, Areva, CEA and EDF must remain vigilant during earthworks or decommissioning work on nuclear sites and take account of the possibility of discovering other legacy disposal sites on these occasions.

R5 – The licensees must take steps to ensure that a record of legacy disposal sites is maintained.

The main legacy waste repositories identified and the monitoring measures implemented are presented below. The particular case of the waste contained in the ponds on the Malvési site is dealt with in Chapter 4.3 of this PNGMDR.

The "Bugey" mound

About 130 m^3 of ion exchange resins (not radioactive according to the criteria used at the time) were buried between 1979 and 1984 on an artificial mound of about 1 million m^3 of backfill and were revealed in 2005 during the initial siting studies for the ICEDA facility to the south of the Bugey site. This mound consists of various natural excavated materials and non-radioactive waste produced by the construction of the various production units. The quality of the groundwater in this area is monitored by eleven observation wells distributed around the mound.

The Pierrelatte mound

The mound, with a surface area of about 37,000 m², was created in the early 1960s. Between 1964 and 1977, trenches were dug for disposal of about 15,000 m^3 of waste, including diffusion barriers and filters, fluorites produced by the processing of uranium and chromated sludges. A plan to monitor the quality of the groundwater has been in place since 1998. The continued operation of the northern part of this mound was authorised with ICPE status: "Storage of legacy waste on the Pierrelatte site", after positioning of an impermeable cover in 2013.

The Pierrelatte north zone

Waste from the decommissioning of the building which housed the uranium enrichment pilot using chemical processing (CHEMEX process), which was shut down in 1989, were disposed of in twelve retention pits in the north zone. This waste represents a volume of about 3,000 m^3. A clean-out pilot project was conducted in late 2010 and early 2011 on two pits, to confirm the nature of the buried waste (rubble, earth and pebbles). The waste from these two pits (about 100 m^3), contaminated with natural uranium and mercury, has been partly packaged and stored pending the availability of a disposal route.

The inert waste storage zone (ZEDI) on the Cadarache site

The ZEDI is a waste burial zone created when the centre was opened and in which 192,000 m^3 of inert waste were placed between 1961 and 2007, including 1,650 m^3 of contaminated waste (4,600 MBq) buried between 1963 and 1991. The observation wells network was completed in 2002 and is used to monitor the groundwater.

Building 133 on the Saclay site

VLL waste backfill (17 m^3 of old earthenware piping debris and 57 m^3 of rubble and earth) was used in the North and South foundations of building 133 on the Saclay centre. Possible retrieval could be eventually envisaged when building 133 is dismantled (not currently scheduled).

Concreted pond in the Marcoule former cladding removal pilot unit

This is an old pond in the STEL which was equipped for underwater fuel cladding removal for a few months, before the cladding removal facility came on-line in 1959. This semi-buried pond was then entirely filled with concrete, with some of the machines and equipment used for the cladding removal process left inside it. The total volume of this pond is 1,116 m^3 and it is entirely isolated from the process, as all the piping was removed and the upper part was sealed. A quarterly surface contamination check is carried out by CEA. No anomaly has to date been detected.

The Marcoule internal depot

This is a depot of about 126,000 m^3 in the Visiatome zone. The investigations carried out show no radiological contamination but this zone is classified in the same way as the ZEDI zone (see above) as a precaution and to ensure consistency with the management practices implemented over time in the various centres.

The trenches in the Marcoule CDS north zone

From 1963 to 1993, four trenches of a total of about 50,000 m^3 were operated in turn in the CDS north zone, to take low and very low level nuclear waste. This waste consists mainly of rubble and soils which at the time did not need to be packaged in drums and for which removal to a conventional landfill was not acceptable.

The experimentation shafts in the Moronvilliers experimentation centre (PEM)

There are about a hundred shafts containing residues from the Defence programme experiments carried out there. These shafts have been filled in and capped. During the survey of polluted sites and soils, CEA declared the PEM site in the BASOL database in May 1997. The entire site, including the hundred or so shafts, is the subject of reinforced environmental surveillance, the results of which are regularly transmitted to ASND and to the Prefect.

The first six conventional waste repositories at Valduc

Until the early 1990s, owing to the isolated nature of the centre, household and general industrial waste, along with rubble, were dumped at six locations on the centre, in compliance with the standards of the period and the practices of all French communes. These sites mainly concerned general, non-hazardous materials, dumped in hollows in the ground. The waste and rubble was thus used to level out the areas in question. Radiological contamination cannot be totally ruled out, owing to the former decontamination practices. The volumes concerned were considerable (estimated at from 100,000 to 150,000 m^3) and their level of radioactive contamination was estimated at nil or very low by CEA, which does not envisage any retrieval operation. These disposal areas are however under surveillance, more specifically by means of observation wells situated downstream of the disposal zones, which ensures that there is no escape of any radioactive element liable to pollute the groundwater.

The Valduc 045 disposal area

This area mainly received contaminated earth from the remediation work in the "Au tilleul" valley carried out in 1995. It consists of a silo, the bottom and sides of which are lined with a membrane, sandwiched between two layers of geotextile fabric, with the assembly then covered with sand. Containment is thus guaranteed. The activity of this earth is low level (average of 1 Bq/g and at most less than 10 Bq/g). The volume concerned is 8,990 m^3. This disposal area is however under surveillance, more specifically by means of observation wells situated downstream, which ensures that there is no escape of any radioactive element liable to pollute the groundwater.

A total of about ten legacy disposal sites have so far been identified on or near the nuclear installations. These disposal sites, apart from Areva NC in Malvési (ex-Comurhex), represent a few tens of thousands of cubic metres of primarily VLL waste, distributed among about 1.5 million m^3 of conventional waste (mainly soil and rubble).

With regard to the management strategies currently planned and implemented by the licensees for the disposal sites identified:

- EDF states that the legacy repositories contained in pools A1 (rubble) and A2 (biological shielding) at Chinon and Chooz A (rubble in area HN041) will be removed and sent to routes dedicated to radioactive waste when the facilities are dismantled;
- Areva, CEA and EDF (apart from the above case) state that to date, no external management route is envisaged, given the absence of environmental contamination. The legacy repositories considered are monitored as part of the more general programmes of site environmental surveillance and steps are taken to maintain a record of the presence of waste (definition of specific institutional controls taking account of the nature of the activity, its history and any residual risks) as and when necessary.
- Areva, CEA and EDF state that, in the event of significant environmental contamination attributable to a legacy waste repository, management solutions would be identified on a case by case basis, according to a "cost/benefit" analysis factoring in all the environmental impacts.

ASN and ASND issued their opinions on 9th February 2016[97] and 29th April 2016 on the studies transmitted by the licensees.

R6 – The waste discovered during the investigations involved in the search for legacy disposal sites should preferably be managed in existing or planned routes, especially when the quantities and nature of the waste so allow.

R7 – When the licensee states that it is in favour of continued in-situ management of a legacy disposal, its arguments shall be sufficiently substantiated, including in terms of costs, to enable the reasons for this choice to be assessed by comparison with the safety issues and the protection of the interests mentioned more specifically in Article L. 593-1 of the Environment Code. Analysis of the in-situ management modes should also take account of the possibility of taking additional measures (environmental consolidation systems, etc.).

R8 – The data explaining the management modes selected by the licensees for each legacy disposal site shall be submitted before the end of 2017.

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[97] ASN opinion 2016-AV-0255 on studies for the management of legacy waste disposal sites is available on the website: http://www.asn.fr, heading « les actions de l'ASN », « la réglementation », « bulletin officiel de l'ASN », « avis de l'ASN ».

3.1.4 The legacy repositories for waste with high natural levels of radioactivity

Several tens of depots for waste containing high natural levels of radioactivity are present around France. This concerns phosphogypsum waste from the production of fertiliser, alumina production residues and coal ashes from thermal power plants, some of which can still be reused. Moreover, some urban construction work in the past also used materials from conventional industry as backfill, even though it comprised slight radiological activity. This is the case with the La Rochelle port areas, in which the installations were in-filled with residues from the former activities to produce rare earths from monazite ore.

An initial inventory[98] of the situation of these sites was produced for ASN by the Robin des Bois association in 2005 and 2009. About fifty sites were identified, of which 46 were depots for ash, five for phosphogypsum and five for alumina production residues. Most of these sites are no longer in service and have either been redeveloped, or cleared out (reuse): they are thus considered to be legacy repositories of waste with high natural radioactivity. About ten are still in operation for reuse of ashes. The five sites for the disposal of residues from alumina production from bauxite are identified in the Provence-Alpes-Côte d'Azur region, in: Vitrolles, Aygalades, La Barasse Saint Cyr, La Barasse Montgrand and Gardanne (this site is still in activity and operated by the RIO TINTO ALCAN company).

The identified sites are covered by the order of 25th May 2005[99] which requires that the licensees of facilities utilising raw materials naturally containing radionuclides not used for their radioactive properties perform a study to measure the exposure to ionising radiation of natural origin and evaluate the doses to which the population and workers are liable to be subjected. Pursuant to this order, the main two operators EDF and E.ON France (ex. SNET) each submitted their generic study in 2007 on the radiological impact of the thermal power plants combustion ashes disposal sites, demonstrating that no dose received by either the population or the workers exceeded 1 mSv/year[100].

In order to confirm the results of the generic studies and take account of the HCTISN[101] recommendations in order to improve data on radiological and chemical contamination of the groundwater of the sites on which radioactive waste has been stored, the authorities asked[102] the current licensees of coal-fired thermal power plants to carry out radiological checks around the combustion ash depots. These checks include the performance of two groundwater sampling campaigns (one at high water and the other in a period of low water) representative of possible contamination by radionuclides resulting from the on-site storage of combustion ashes from

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[98] The reports drawn up by Robin des Bois are available on the site www.robindesbois.org: « la radioactivité naturelle technologiquement renforcée » and « les cendres de charbon et les phosphogypses ».

[99] Order of 25th May 2005 concerning professional activities involving raw materials naturally containing radionuclides not used for their radioactive properties.

[100] This dose corresponds to the maximum allowable dose for the "public" set in Article R. 1333-8 of the Public Health Code: "the sum of the effective doses received by any person not in the categories mentioned in Article R. 1333-9, as a result of nuclear activities, shall not exceed 1 mSv/year."

[101] See HCTISN opinion of 6th November 2008 on the radio-ecological monitoring of the waters around nuclear facilities and on the management of former radioactive waste storage sites.

[102] See the 18th June 2009 circular concerning implementation of the HCTISN recommendations, which require a guarantee that on radioactive waste disposal or storage sites (outside BNIs and SBNI), environmental monitoring is adequate, with appropriate measurements being taken (notably by means of targeted measurement campaigns).

thermal power plants, and the study of atmospheric exposure routes by analysing dust in the air on sites where this risk is liable to occur.

The progress made in the sampling campaigns on the former coal ash depots is as follows:

- for depots under EDF responsibility:
    - the analysis of the groundwater on the priority sites (Blénod, La Maxe, Bouchain, Le Havre et Cordemais) reveals no particular anomaly;
    - the sites on which operations have ceased (Champagne-sur-Oise, Vaires-sur-Marne, Allennes-les-Marais, Pont-sur-Sambre, Beautor and Saint-Leu-d'Esserent) were also analysed. The conclusions were released and show no particular anomaly;
    - analyses are still required on certain particular sites (absence of ashes, the licensee is no longer the owner, etc.);
- for the depots belonging to the licensee E.ON (SNET), the measurement campaigns were performed and show no particular anomaly;
- for the depots of the other licensees (Akzo-Nobel, Colas, Surchiste, Vermeulen-SA, some of whom reutilise the ashes): certain studies are in progress, while others have already been submitted and are being examined;
- for the fourteen sites which were the responsibility of Charbonnages de France, the radiological impact of the ash disposal sites was evaluated in September 2010 on five sites in Nord-Pas-de-Calais (Choques, Dechy, Fouquereuil, Fouquières-les-Lenz, Hallicourt) by the BRGM and IRSN[103]. The radiological impact associated with the ash repositories on the sites examined is negligible and indicated no transfer of pollution to the groundwater. For the other nine sites where there is no longer an identified licensee, the BRGM and IRSN looked for any radioactive pollution linked to the presence of coal ash, at the request of the DGPR. The studies conducted between 2012 and 2014 revealed no impact by these depots.

Similar measures are also under way for the phosphogypsum depots resulting from the production of fertiliser (five depots have so far been identified: Anneville-Ambourville, Saint-Etienne du Rouvray, Rogerville, Douvrin, Wattrelos), for which radiological monitoring is currently under way, notably for the groundwater.

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[103] The report is available on the website Le http://www.nord-pas-de-calais.developpement-durable.gouv.fr, heading « la dreal », « actualités », « dépôt des cendres de charbon ».

3.2 Management of mining processing residues and waste rock

In France, the uranium mines were worked from 1948 to 2001. The exploration, extraction and processing activities concerned about 250 sites in 27 French *départements*. Ore was processed in eight plants.

Exploration and the working of the uranium mines generated:

- "waste rock" consisting of rock excavated to access economically useful ore;
- "processing residues" consisting of products remaining after extraction by processing of the uranium.

Given the large quantities of waste produced, the management method currently adopted for these substances is in-situ management, including verification of the steps taken to limit the current and long-term impact to a level that is as low as reasonably achievable. The mining residues disposal sites are subject to the regulations on installations classified on environmental protection grounds, under the responsibility of Areva.

The studies conducted by Areva mean that it is now possible to assess some of the long-term impacts of the processing residues disposal sites. Those included in the 2013-2015 PNGMDR in particular led to:

- the provision of data concerning modelling of the impact of the mining residues disposal sites;
- improving understanding of the phenomena of uranium transport from the mining waste rock pile heaps to the environment;
- improving understanding of the mechanisms regulating uranium and radium mobility within uranium-bearing mining residues.

With regard to mining waste rock, Areva is continuing to process the places on which it is reutilised, outside the perimeter of the former mining sites, within the framework of the survey initiated in 2009.

With regard to the treatment of water and the impact of discharges from the former mining sites, the interim report submitted provides data to help assess the strategy for changes to the treatment of these waters from former mining sites.

With regard to the embankments around the residues disposal sites, the work done by the PNGMDR working sub-group means that a methodology is now available for assessing their long-term mechanical strength.

These various studies will need to be continued for the next two PNGMDR in order to complete the studies into the long-term evolution of the mining waste rock processing residues, complete the methodology for assessing the long-term strength of the embankments, study the possibilities for modifying or shutting down the water treatment plants and, finally, to propose concrete measures to reduce the risks and impacts on the various sites. With regard to mining waste rock, treatment of those sites with outdoor waste rock must be continued.

The consultation process must also be continued with the stakeholders on all these subjects, within the framework of the PNGMDR, but also at the local level.

3.2.1 Context and issues

In France, the uranium mines were worked from 1948 to 2001, leading to the production of 76,000 tons of uranium. The exploration, extraction and processing activities, from simple survey work to large-scale exploitation, concerned about 250 sites in France in 27 *départements*. Ore was processed in eight plants.

Most of these sites are described in the "MIMAUSA"[104] National Inventory of uranium mining sites produced by IRSN in 2004 at the request of the Ministry responsible for the environment and it is regularly updated.

The working of the uranium mines produced about:

- 170 million tons of **mining waste rock,** which is the soil and rock excavated to access the economically useful ore with, on the one hand, the barren rock in which the average uranium content corresponds to the characteristic level of the natural ambient background level[105] and, on the other, the sub-grade ore consisting of ore-bearing rock excavated during working of a deposit but in which the contents were not high enough to warrant economic processing (contents which fluctuated over time across a range of between 100 and 400 ppm[106]);
- 50 million tons of **processing residues** which cover the products remaining after static or dynamic extraction of the uranium from the ore. The residues correspond to process waste as defined by the Environment Code and the disposal sites are ICPEs in accordance with section 1735.

Most of the mining waste rock has remained on the production site, used to fill in open-pit mines or underground mining structures such as shafts and has been used for remediation work to cover over residue disposal sites or placed in spoil heaps. Areva estimates that about 2 million tons of mining waste rock[107] or 1 to 2% of the extracted volumes, may also have been used as infill, earthworks or road base layer materials in locations outside the perimeter of the mining sites.

The processing residues are disposed of on seventeen sites[108], all close to the uranium ore processing facilities and correspond to VLL or LLW/LL type waste, characterised by their grain size distribution and their specific activity.

About 20 million tons are **ore processing residues with low average content** (average total specific activity of 44 Bq/g, including about 4 Bq/g of radium 226), resulting from static leaching. They are disposed of either on rock piles or in open-pit mines, or used as the first covering layer of dynamic leaching processing residue repositories;
Ore processing residues with a high average content (average total specific activity of 312 Bq/g, including about 29 Bq/g of radium 226), resulting from dynamic leaching and disposed of in former open-pit mines, sometimes with an additional embankment, or in ponds closed by a surrounding embankment or behind an embankment closing off a thalweg, representing about 30 million tons.

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[104] The MIMAUSA inventory (History and impact of uranium mines: Summary and Archives) is accessible on the IRSN website: http://www.irsn.fr, heading « accueil », « base documentaire », « environnement », la surveillance de l'environnement », « les sites miniers d'uranium ».

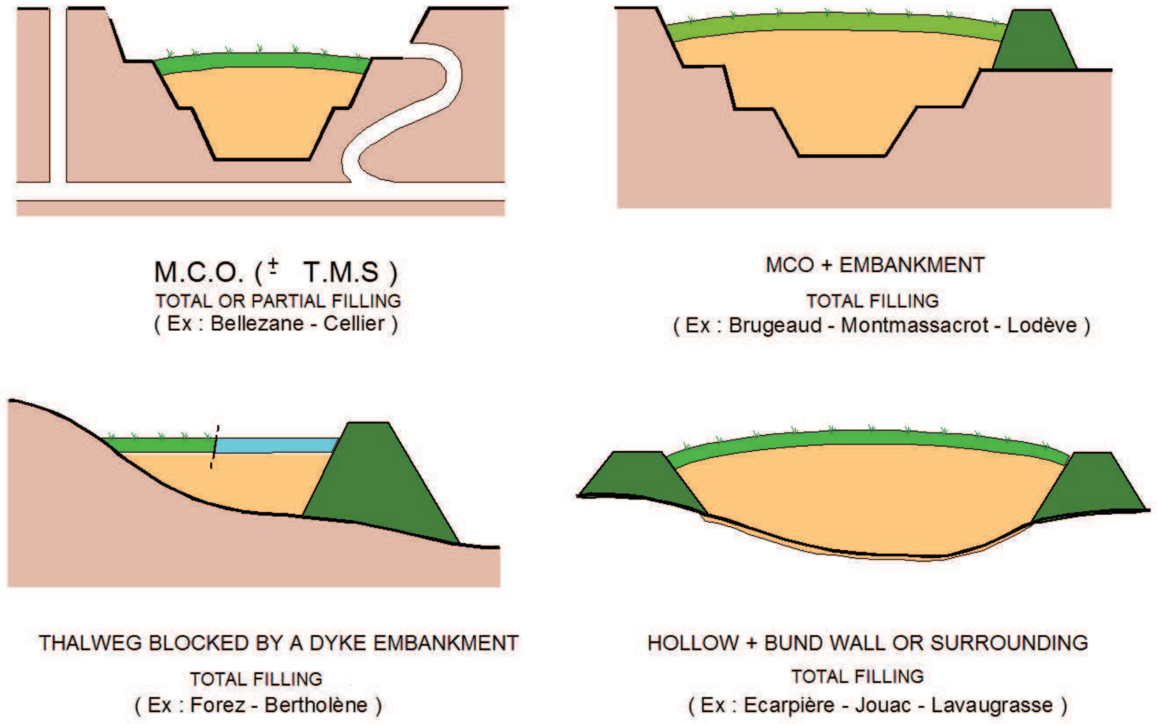
[105] For example, the characteristic ambient background level is between 0.4 and 2.5 Bq/g U natural in the Limousin region.

[106] That is rocks with a total activity of less than 8 Bq/g.

[107] According to Areva, the total activity of the waste rock reutilised is less than 2.5 Bq/g

[108] These disposal sites cover a surface area of from one to several tens of hectares and contain several thousand to several million tons of residues.

Rehabilitation of the residue disposal sites thus consisted in placing a solid cover over the residues, to provide a geomechanical and radiological protection barrier designed – in accordance with the optimisation principle - to mitigate the risks of intrusion, erosion and dispersion of the products in place and the risks related to external and internal exposure of the surrounding populations to radon. Public access to these residue disposal sites nonetheless remains prohibited.



M.C.O. (± T.M.S)
TOTAL OR PARTIAL FILLING
(Ex : Bellezane - Cellier)

MCO + EMBANKMENT
TOTAL FILLING
(Ex : Brugeaud - Montmassacrot - Lodève)

THALWEG BLOCKED BY A DYKE EMBANKMENT
TOTAL FILLING
(Ex : Forez - Bertholène)

HOLLOW + BUND WALL OR SURROUNDING
TOTAL FILLING
(Ex : Ecarpière - Jouac - Lavaugrasse)

Different types of mining residue disposal sites
(MCO: open-pit mine, TMS: underground mine-workings)

The other mining sites were also rehabilitated in accordance with the same optimisation objective. Unlike the residue disposal sites, most of the land concerned was restored to its use prior to exploitation of the mines, or was sometimes redeveloped for new uses[109].

3.2.2 Regulatory framework

The uranium mines and their annexes are covered by the mining code. The Mining Code was created by the decree of 16th August 1956 on the basis of the basic mining act of 21st April 1810. The resulting notion of the mine depends on the nature of the material, whether extraction is in an open-pit or underground mine. In France, common law states that "ownership of the ground includes ownership of what is above and below it" (see Article 552 of the Civil Code). The Mining Code however nuances this rule by specifying that "mines" substances can be conceded by the State. They are thus outside the law of ownership and the State attributes the use and sets the conditions of mine operation.

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[109] For example, an open-pit mine flooded after closure, was redeveloped as a reservoir and diving centre.

The materials concerned are all substances of use to the economy, the list of which is set by Article L.111-1 of the Mining Code, such as fuels (coal, oil and gas), metals (nickel, gold, iron, copper, uranium, etc.), other substances liable to have industrial (carbon dioxide, salt, sulphur, etc.) and geothermal uses.

In mining law, there is a clear difference between:

- Exclusive mining rights to the substance: an exclusive exploration license, or a mine-working concession. The concessions awarded for the uranium mines are recent and of "limited" duration set by their creation decrees. Only the concessions awarded for uranium mines between 1810 and 1991 and between 1955 and 1977 have a duration for which the expiry date was subsequently set on 31st December 2018[110].
- The beginning of exploration or mine-working: granted by decision of the Prefect (notification or license) by virtue of the mining policing authority exercised by the Prefect without necessarily obtaining the consent of the owner of the land. This license relates to the exploitation of the substance (substantial exploration and mining work) and sets the conditions for working the mine in compliance with the various interests set by Article L.161-1 of the Mining Code. At the end of the mine-working phase, making the mine safe and protection of the interests mentioned in Article L.161-1 require a cessation of works procedure.

  The radiation protection risks are governed by the prescriptions of Decree 90-222 of 9th March 1990, supplementing the general regulations of the mining industries, created by Decree 80-331 of 7th May 1980 with regard to protection of the environment from radioactive substances. This decree is currently being revised.

Following the work to close and rehabilitate a former mining site, urban development may need to be controlled, more specifically as part of the long-term management of the sites. Several tools for controlling urban development may be implemented, such as the public information notice (PAC) sent out to the communes concerned or the mining risks prevention plans (PPRM). The main purpose of these tools is to ensure individual safety, while allowing acceptable quality of local life and mitigating risks to property.

Mining processing residues are considered to be industrial waste subject to the provisions of the regulations applicable to ICPEs[111] and disposal sites for these residues are subject to a licensing system in conformity with section 1735 of the ICPE nomenclature.

Finally, concerning the management and regulation of former uranium mining sites, the Ministry for sustainable development and ASN defined an action plan, in a circular of 22nd July 2009, comprising the following four areas of work:

1. monitor the former mining sites (inspections);
2. improve understanding of the environmental and health impact of the former uranium mines, plus surveillance and monitoring (in particular environmental reports requirement);
3. manage the waste rock (better understanding of its uses, survey the places where reused in the public domain, assess its dose impact and reduce impacts if necessary and if incompatible with the usage);
4. reinforce information and consultation.

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[110] For example, concessions awarded for uranium for which the duration is set by their creation decree: La Varenne (2035), Champ Grenier (2039), Blanchetierre (2041) concessions and La Maillerie (2041) concession. For information, the concessions granted for uranium between 1919-1955 are of limited duration, while those granted between 1955-1977 are in perpetuity and those granted after the 16th June 1977 Act amending the Mining Code are of limited duration.

[111] See Title 1 of Book V of the Environment Code, and in particular its Article R. 511-9.

3.2.3 The work of the Limousin pluralistic expert group

A pluralistic expert group (GEP)[112] for the Limousin uranium mines was set up in 2006 by the Ministers for sustainable development, industry and health, as well as by ASN, in order to specify the long-term management issues for the former mining sites and disposal sites for the waste generated, to create a process of dialogue and consultation around the former uranium mining sites. The GEP approach was initiated on the basis of a detailed analysis of certain sites in the Limousin region (the region most concerned by past mining) in order to develop a broader vision of the situation of the former uranium mining sites in France. The conclusions and recommendations of the GEP concerning the short to long-term management and development of the regulatory framework concerning the former uranium mining sites in France, were returned in 2010.

In a letter of 25th April 2012 to the GEP President, the Director General for the prevention of risks and the Director General of ASN clarified how the recommendations made were to be taken into account. The public authorities decided to divide the GEP's fifteen main recommendations into the following four topics:

- modernising and clarifying the institutional, regulatory and doctrine-related framework,
- improving the knowledge and management of the sites,
- improving scientific and technical knowledge,
- taking account of the other various recommendations.

At the same time, the public authorities asked the GEP to present its recommendations to the local stakeholders. Following this work, the GEP submitted a report to the public authorities on 4th November 2013, thus closing more than 7 years of work on the legacy of uranium mining operations in France. The GEP's work underlines the need to continue with and supplement the ongoing initiatives to achieve overall management of the long-term fate of these sites. It also restates the importance of the pluralistic aspect which it spearheaded and calls on all the national and local stakeholders to take over from where it left off.

3.2.4 The issues related to uranium mining operations

Several issues are involved in the redevelopment of the former uranium mining sites[113]:

- surveillance of the redeveloped former mining sites;
- management of diffuse releases and water treatment;
- mitigation of the impacts on people and the environment;
- oversight of the reuse of redeveloped former mining sites and the materials linked to this operation (waste rock, residues).

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[112] The role of the GEP Limousin was to ensure regular monitoring of the third-party assessment of the operating report transmitted in December 2004 by Areva NC and to take part in its coordination. Its role was therefore to make a critical appraisal of the situation of the former uranium mining sites, to inform the administration and licensee of the management prospects for the medium to long-term and to inform the local stakeholders and the public of its work and its conclusions. Four working sub-groups were defined: source term and releases, environmental and health impact, long-term regulatory framework, measurements.

[113] The terminology "former uranium mining sites" is used in the broadest sense and includes all types of extraction facilities which were operated on the site and during the course of its history (open pit mines, underground mining work) but also if they were transformed into a mining processing residues disposal site.

The GEP identified several consequences of mining operations, which constitute potential sources of chemically or radiologically toxic products, the operation of which can have an impact on man or the environment[114]:

- underground and open-pit mine workings (TMS and MCO),
- waste rock heaps,
- mining residue disposal sites,
- mining waste rock reused outside the perimeter of the former mining sites,
- soils and sediments constituting areas in which there is a build-up of radionuclides.

It would seem to be worth recalling that even if certain sites have been redeveloped, their rehabilitation must nonetheless be continued with a view to their long-term management. It remains necessary to continue to treat the water collected before it is discharged. The reduction of releases and the improvements in water treatment, more particularly with respect to changing uranium discharge standards and with preference being given to "green techniques[115]", are in this respect key issues, particularly with regard to the impact on the surrounding environment. In this respect, the analysis of current water treatment practices on the mining sites and of the associated liquid discharges, must take account of all chemical and radiological risks and must analyse their environmental impact, particularly on the contamination of sedimentary build-ups in rivers, lakes and wetlands.

3.2.5 Management of former mining sites

Most of the sites have already undergone work to make them safe following the cessation of operations. The former uranium mining sites are eventually expected to return to conventional land ownership practices (public or private property). First of all, it is up to the licensee to carry out the necessary work to mitigate the impact of these sites on the environment. It is therefore up to the public authorities to define the requirements enabling this goal to be achieved and to assess the effectiveness of the work done within the framework of regulatory works completion procedures (second confirmation of closure, document regulating the long-term monitoring of the site).

3.2.6 Management of diffuse releases and water treatment

As mentioned above, direct and diffuse discharges must be reduced and discharge treatment improved, in particular in terms of the impact on the surrounding environment.

After evaluating current water treatment practices[116] in use on its sites, Areva submitted an interim report on the approach it has initiated on all the treatment plants, in order to define and justify the development strategy adopted (shut down, maintain, modify or implement new processes) for

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[114] See p. 54 of the final report from the GEP Limousin, September 2010.

[115] Technique with no chemical input or low impact on the surrounding environment.

[116] 10 stations use a physico-chemical precipitation settling process, 3 use limestone drains and 1 uses ion exchange membranes.

processing of the water collected on the former mining sites under its responsibility. This report dated 17th February 2015[117] contains the following for certain treatment plants:

- a description of the treatment processes,
- identification of the origin of the treated waters,
- information concerning the changes in their quality and the impact of the treatment plants on the environment,
- information concerning maintenance and management constraints regarding the sludges produced by the treatment stations
- and, finally, a proposal for an evolution of the strategy.

This information is currently being analysed. In accordance with the request made in the 2013-2015 PNGMDR, a final study will be submitted within the framework of this PNGMDR. This study will, as necessary, include the comments resulting from the ongoing analysis of the interim report and will formally set out a strategy for the continued treatment per site (shut down, maintain, modify, or implement new processes) to be proposed to the locally competent services. It will also include changes in scientific knowledge, more particularly concerning the long-term changes occurring in mining waste rock and mining residues, in order to identify the geochemical mechanisms which will influence the natural evolution of the quality of the waters from uranium mining sites and the changes to the standards regulating uranium discharges into the waters, in line with the objectives of the framework directive on water and in accordance with the revised environmental quality standards published.

R1 – AREVA will consequently need to continue and expand on the approach already underway on some of the treatment plants, extending it to all the treatment plants for the waters from former uranium mining sites, in order to define and justify the strategy to adopt (shut down, maintain, modify or implement new processes) for processing of the water collected on the former mining sites under its responsibility. The strategy that will be adopted shall in particular be justified with respect to:

- **foreseeable natural changes in the quality of the water on each of the sites, in the light of the geochemical mechanisms involved and the trends observed to date;**
- **the aim of reducing the overall impact of discharges on man and the environment, taking account of the chemical impact associated with the various substances discharged, including those linked to the water treatment processes;**
- **the constraints involved in managing and eliminating sludges and waste associated with the various processes used or studied;**
- **maintenance constraints for the processes envisaged and the priorities regarding the deployment of possible alternative solutions.**

An interim review is requested for 31st December 2017.
The complete report on this approach is required for the time-frame of the 2019-2021 PNGMDR.

R2 – ASN and the DGPR will continue to oversee the investigations within the PNGMDR working group concerning the choice of continuing with treatment (while improving it whenever necessary) or putting an end to treatment of wastewater from the former uranium mining sites in the light of the various criteria, especially the assessment of the overall

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[117] The report submitted by Areva is available on the websites of ASN and the Ministry responsible for energy:

- http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015 ;
- http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

impact (radiological and chemical) of the discharges on the receiving environment. This choice requires prior definition of foreseeable development scenarios for the characteristics of the water collected, taking account of the geochemical processes involved and the trends observed.

I1 – Percentage of treatment plants for the waters from former uranium mining sites, for which the strategy for the future of the treatment of the water collected on the former mining sites (shut down, maintain, modify or implement new processes) has been defined.

The impact assessments conducted by Areva also provide important lessons for assessing the impacts associated with the various substances discharged and thus for defining the optimisation possibilities on which to focus. The contribution of the chemical component of the discharges would in particular appear to be predominant in estimating their possible environmental impact. This contribution is especially significant for uranium but also for the barium added to the discharges by the treatment. At this stage of the risk assessment, the results obtained by Areva for these two elements cannot rule out the existence of a potential risk for the aquatic ecosystems in the receiving watercourses. The assessments will need to be continued as part of the mining works final shutdown procedure. The works carried out at European level as part of the ERIKA programme will also need to be taken into account.

The 2013-2015 PNGMDR revealed the need to improve knowledge concerning the contamination of sediments in ponds and lagoons, watercourses or wetlands, linked to the quantities of uranium and radium discharged into the hydrographic network after treatment and to diffuse discharges. To do this, Areva submitted two interim reports concerning the connection between the volume of discharges and the build-up of contaminated sediments in rivers and lakes, in particular comprising a study of the speciation of uranium in the waters of the former Bois Noirs Limouzat mine and a characterisation of the sediments in Saint Clément lake situated downstream of the site. According to the initial data collected, Areva concluded that the uranium in the discharges from the Bois Noirs Limouzat site is in soluble form and its speciation means that it is not bioavailable. Areva also found that no radiological contamination was observed in the water body downstream of the site, except at the point of entry to it, with this contamination dating from the period during which the site was redeveloped.

R3 – Areva will supplement the study on the connection between the discharges from the Bois Noirs-Limouzat site and the build-up of contaminated sediments in Saint-Clément lake with the results of microbiological characterisations and those of analyses of the interstitial waters in the sediments in Saint Clément lake.
This study is requested for 31st December 2016.
R4 – Subsequently, Areva will supplement this study with:

- **modelling of transfers from the mining sites to the sediment build-up areas downstream, on the basis of the characterisation results acquired in the La Besbre catchment basin. This modelling shall make it possible to determine the dynamics of the build-up of the stock of contaminated sediments;**
- **modelling of the transfer of fixed radionuclides to the carrier phases of the sediments for various sediment management scenarios applied to the sediments of the La Besbre catchment basin, in order to obtain data essential for reaching a decision on the management of these sediments.**

An interim report is requested for 31st December 2018.

3.2.7 Dosimetric impact

The methodology for assessing the long-term dosimetric impact of residue repositories was adapted by Areva to the case of waste rock piles in accordance with the first request of the 2007-2009 PNGMDR. Four scenarios were studied for waste rock piles: the normal evolution scenario and three altered evolution scenarios, which are a residential construction on the waste rock pile, a road-building construction site and a children's playground. Regardless of the scenario, the assessments made by Areva identify a waste rock pile activity level of from 0.8 to 2.5 Bq/g. The calculated doses thus obtained all remain below 1 mSv/year[118].

Areva used its knowledge of the sites, more specifically through the environmental reports[119] required by the circular of 22nd July 2009, to identify the presence of waste rock piles. In an interim report dated 17th December 2014[120], Areva presents an inventory of 165 waste rock piles present on the former uranium mining sites in France.

R5 – Areva will continue the process to survey waste rock piles, more specifically through the environmental reports required by the circular of 22nd July 2009, specifying:

- **those with the most significant uranium contents,**
- **the levels of exposure with which they could be associated in the various conceivable scenarios,**
- **the utilisation or rehabilitation situations identified on these sites.**

This information shall be made available to the public in the MIMAUSA database. These actions shall be finalised before 31st December 2017.

I2 – Number of waste rock piles inventoried in the MIMAUSA database.

As required by the 2013-2015 PNGMDR, Areva carried out a study to check the presence or absence of the risks of environmental contamination from the waste rock piles. The interim report dated 9th July 2013 shows the detailed mineralogical characterisations of the phases making up the altered and unaltered waste rock piles[121], in particular the uranium carrying phases. On the basis of these initial results, Areva concluded that the risks of environmental contamination from the waste rock piles are limited because the uranium is mainly carried by the minerals with low reactivity (refractory minerals resistant to weathering, secondary phosphated minerals such as autunites with low solubility, clayey minerals able to immobilise the uranium by sorption). The study of the phenomena of uranium transport from the waste rock piles to the environment, using the corresponding geochemical modelling simulating the various foreseeable disturbances as the site evolves, will be continued within the framework of this PNGMDR.

R6 – Areva will continue the process initiated to study mining waste rock from the former uranium mines in France, in particular with regard to the long-term evolution of the mining waste rock and, for the sites identified in its study, will develop geochemical models to predict uranium migration from the waste rock piles to the environment, taking account

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[118] Regulation value stipulated in the Public Health Code for assessing the compatibility of the observed usages with the observed contamination. It should be noted that it also corresponds to the order of magnitude of exposure of natural origin, excluding radon, which mainly results from exposure to radiation of telluric and cosmic origin.

[119] The environmental reports corresponding to the operating reports mentioned in the circular of 22nd July 2009.

[120] The report submitted by Areva is available on the websites of ASN and the Ministry responsible for energy:

- http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015 ;
- http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

[121] Waste rock from the former mining sites of Bellezane, Pény and Margnac.

of the possible usage change scenarios as well as the foreseeable long-term disturbances (loss of waste rock pile integrity, changes in usage, climatic event, etc.). Areva shall demonstrate that its conclusion of low uranium mobility is consistent with the environmental contamination observed on the sites.
This study is requested for 30th June 2018.

R7 – Areva shall then verify and, as applicable, complete its study to ensure that its model is representative of all types of waste rock piles (sedimentary context, hydrogeological condition, etc.). This study is requested for 31st December 2019.

3.2.8 Long-term management of ore processing residues disposal sites

Processing residues have been disposed of on seventeen sites. The method adopted is in-situ management given the large quantities of waste produced and following verification that the steps taken can limit the long-term impact for as long as reasonably achievable.
As was underlined by the GEP and the public authorities, it would also appear necessary to have an institutional, regulatory and doctrine-related framework appropriate for this long-term management perspective for the mining residue disposal sites and certain former mining sites. To this end, ASN and the Ministry for the environment, energy and the sea set up a working group in 2012 to address this recommendation. Draft guidelines, overseen by the DGPR, concerning administrative doctrine for management of uranium mining sites are currently being finalised.

3.2.9 Long-term evolution of uranium ore processing residues

With regard to evolution of the long-term physico-chemical characteristics of the ore processing residues, the study submitted by AREVA for the 2007-2009 PNGMDR, indicates that the residues evolve naturally towards a mineralogical and chemical form which significantly limits the mobility of the uranium and radium. The studies requested for the 2013-2015 PNGMDR, submitted on 21st November 2014, aimed to consolidate the methodology used, by supplementing the data already transmitted, incorporating the static processing residue disposal sites[122], in order to confirm the possibility of extrapolating them to the disposal sites not yet studied. In this report, Areva selected four sites[123] illustrating the various geological and hydrogeological contexts and the various types of processing of the uranium ore present on the disposal sites. Areva is studying the results of the characterisations of the mineral phases of the residues and the chemical and radiological composition of the waters. Areva observes the same families of minerals on all the sites, which confirms the results of the previous studies. Areva notes that the uranium is retained by sorption on the clayey minerals and the iron hydroxides, while the radium is retained by incorporation into the barite. With regard to their mobility, Areva specifies that for uranium it will depend on its interactions with the phosphated minerals present in the residues and, for radium 226, on the presence of barite. These studies will be continued within the framework of the 2016-2018 PNGMDR, more specifically by taking account of these reactional mechanisms in the modelling of the evolution of the source term of the residues on the disposal sites and the evolution of these sites in normal and altered conditions.

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[122] La Ribière and Le Cellier sites.
[123] Lavaugrasse, Bellezane, La Ribière and Le Cellier.

R8 – Areva shall continue and complete the work on modelling the long-term transfer of uranium and radium for the residue disposal sites selected in its study. Areva shall more specifically take samples of residues at depths representative of the hydrogeochemical conditions within the disposal sites, characterise the corresponding interstitial waters and demonstrate the consistency between the uranium and radium conceptual models used for their mobility, the characteristics of the interstitial water thus obtained and the observed environmental contamination.
This study is expected by 31st December 2017.

R9 – Areva shall then verify and, as applicable, complete its study to ensure that its model is representative of all types of uranium mining residue disposal sites. This study is expected by 31st December 2019.

In its opinion of 9th February 2016[124] ASN considers that it will be necessary to extend the approach to the other sites.

3.2.10 Management of long-term dosimetric impact

A monitoring system was set up, based on analysis of all transfer and exposure routes and on identification of the population groups liable to be the most exposed. This radiological impact assessment comes up against a practical problem of evaluating the added dose received by a member of the public, in particular because of the natural radioactivity already present locally and the absence of any baseline benchmark identified when the mines were opened.

Generally speaking, the studies initiated by Areva are recent and utilise the measurements and observations taken during the course of the monitoring of its sites. Measurement data must nonetheless be acquired over a sufficient time-scale and on a representative number of sites. The long-term research work could therefore last until 2020, with interim reviews being conducted every three years, when the PNGMDR is updated.

The modelling methodology developed by Areva in accordance with the doctrine publishes by the Ministry for the Environment in 1998, to assess the long-term dose impacts of the residue disposal sites, comprises one normal evolution scenario and four altered evolution scenarios, to wit: loss of integrity of the embankment and covering, construction of housing above the disposal site, with or without a covering, construction of a road, presence of children playing on the excavated residues. This modelling methodology was applied by Areva to nine disposal sites for ore processing residues, of different sizes and geological contexts. According to the results of the Areva studies submitted for the 2010-2012 PNGMDR, the dosimetric impacts on the population in a normal evolution situation remain below 1 mSv/year in the active monitoring phase and those conceivable for the disposal sites major degraded scenarios remain below a few tens of millisieverts per year.

Areva supplemented this approach in the 2013-2015 PNGMDR with a comparison between the data from this methodology and the environmental monitoring results, initially to boost confidence

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[124] ASN opinion 2016-AV-0254 of 9th February 2016 on evaluating the impact of uranium mining residues and the management of former uranium mining sites is available on the website http://www.asn.fr, heading « les actions de l'ASN », « la réglementation », « bulletin officiel de l'ASN », « avis de l'ASN ».

in its calculation results and secondly to improve the pertinence and usefulness of its sites monitoring system. In the report dated 2nd February 2015[125], Areva presented the comparison between the results of the 2009 studies and the radon exhalation rates measured in the field on 6 disposal sites[126] and concluded that the average rates measured are significantly lower than the theoretical source term rates calculated, which are therefore worst case scenarios. Areva also presented the comparison between the results of the modelling of atmospheric dispersal of radon and the measurements taken by the environmental monitoring stations located around the sites[127]. Areva concluded that the influence of these sites is slight (about 1 to 7% of the background level, except for one site where this figure is as high as 12%) and that the various contributions measured at the monitoring points mainly reflect the variability in the natural background levels. Areva thus specified that the analysis and interpretation of the data do not reveal any significant impact from the residue disposal site.

Areva considers that these results confirm the conclusions of its January 2012 studies that the origin of the various contributions to the total dose is natural and that the covering of the sites is sufficiently effective. Therefore, reinforcing the quality of coverings which, in the light of the long-term impact assessments[128], would appear to be a potentially effective solution on several sites, was not the subject of an additional AREVA study to assess the feasibility and pertinence of this possible reinforcement on all the ore processing residues disposals sites.

This study thus provides new data on the methodology for modelling the impact of mining residues disposal sites but does not allow a conclusion to be reached on the need to size the covers on each mining residue repository.

R10 – The assessment of the impact of the mining residues disposal sites, plus the sizing of the covering of each mining residues disposal site must be analysed within the framework of the work done by the DGPR to define a long-term management doctrine for uranium ore mining residues disposal sites.

3.2.11 The long-term strength of the retention embankments around the mining processing residues disposal sites

In the studies submitted by Areva in January 2012 within the framework of implementation of the 2010-2012 PNGMDR, Areva in particular specifies that the actual construction of the structures offers good long-term stability, owing to their shallow slopes, the absence of a layer of water[129], the gradual drying of the residues and their resulting consolidation. Areva explicitly takes account of the impact of the cessation of upkeep of the sites on the clogging of the drainage networks and on the evolution of the hydraulic conditions inside the embankments. The unfavourable situations liable to result from this scenario are studied in the generic evaluation via the critical hydraulic

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[125] The report submitted by Areva is available on the websites of ASN and the Ministry responsible for energy:

- http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015 ;
- http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

[126] Brugeaud and Lavaugrasse (Haute-Vienne *département*).

[127] Gueugnon (Saône et Loire), Lodève (Hérault), Ecarpière (Loire Atlantique), Bellezane (Haute Vienne), Brugeaud and Lavaugrasse (Haute-Vienne).

[128] Studies carried out pursuant to the 2007-2009 PNGMDR.

[129] Only the Bois Noirs Limouzat site has a layer of water and a replacement project using a solid cover is being studied by Areva.

conditions. Areva also significantly reinforced the level of seismic hazard adopted in order to take account of the lifetime of the residue disposal facilities. Areva sets the disposal facility lifetime to be considered for the long-term stability studies at 1,000 years and the target return period for a seismic hazard at 30,000 years[130]. Areva also raised the safety factor adopted from 1 to 1.2 to estimate the strength of the embankments in the event of external loadings.

A pluralistic working group set up under the 2013-2015 PNGMDR also drafted a methodology for assessing the long-term strength of the embankments around the uranium ore processing residue disposal sites, to a large extent drawing on these studies. For the working group, the verification of the long-term stability of the embankment depends on the analysis of the minimum performance necessary for continued performance of its functions (contain the products and limit transfers to the exterior) despite the hazards (seismic hazards, extreme hydraulic situations) it is liable to face, being maintained. The working group proposes an approach to be followed and methods for assessing the long-term strength of the residue disposal site embankments. However, the structures may have to deal with other hazards: erosion, changes to the materials (physical, chemical, biological of the various components of the structure and the residues), or combinations of hazards which the current level of knowledge is unable to assess. These hazards must nonetheless be taken into consideration in the event of consolidation works being carried out.

In its report of 1st April 2014[131], Areva sent the PNGMDR an action plan and a methodology for compiling geotechnical files and a selection of representative or priority embankments on which stability assessments will be carried out. The methodology will need to be supplemented in the light of the data provided by the "Stability of embankments around uranium ore processing residues disposal sites" working group.

R11 – Areva is required to continue to compile the geotechnical files and apply the methodology defined by the working group on the mechanical stability of the embankments on all or some of its sites. Following this step, Areva will analyse the results of this assessment and return its conclusions on the robustness of the structures for the envisaged lifetimes and will submit proposals for the monitoring and upkeep of the structures or their reinforcement. These conclusions will be based on the one hand on the results of the study of the long-term strength of these structures and, on the other, on the assessment of the possible consequences of a structural failure. These studies are required by 31st December 2019.

R12 – The working group will be consulted by Areva on the implementation of this method on a few cases and will submit its conclusions by 31st December 2017.

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[130] The seismic motions derived from the methods applicable to "special risk" facilities are increased. The regulations for the design of installations classified on environmental protection grounds, sets 3,000 years for the hazard selected. AREVA specifies that the increase adopted for its disposal facilities is equivalent to considering a seismic hazard with a return period of 30,000 years.

[131] The report submitted by Areva is available on the websites of ASN and the Ministry responsible for energy:

- http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015 ;
- http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

3.2.12 Management of mining waste rock

Although since 1984 the transfer of waste rock outside the perimeter of the former mining sites has been traced for the sites operated by Cogema and sometimes carried out in compliance with orders from the Prefect to the quarry operators, the picture remains incomplete with regard to transfers prior to 1984.

The lack of past traceability of waste rock transfers requires a precise survey of the mining waste rock reused in the public domain, in order to guarantee the compatibility of usages and mitigate the impacts if necessary. This issue is the subject of a firm request from the public authorities, detailed in the circular from ASN and the ministry responsible for the environment dated 22nd July 2009.

The generic radiological exposure assessments performed by Areva concerning the most frequently observed cases of mining waste reuse (farmyards, tracks, etc.) lead to added doses which do not in principle exceed the limit of 1 mSv/year[132] for the scenarios and uranium content hypotheses adopted and taking account of the current usage of the sites. However, these results do not take account of exposure to radon in constructions built on land backfilled by mining waste rock.

To regulate this operation, a specific instruction was signed by the DGPR on 8th August 2013. It more particularly specifies the conditions for information of the public concerning the results of the survey, defines the methodology for performance of the works and specifies the means of preserving a record (memory).

Areva submitted a review of this operation in its report of 17th December 2014[133]. The survey was carried out by helicopter-borne checks around former sites which produced 95% of the tons of waste rock (only the communes concerned by mine-working were overflown). For the 17 blocks overflown (2,900 km^2), all the survey maps were transmitted between 2011 and September 2013, while the survey maps for the zones not overflown were transmitted in March 2014. All the maps are at present posted on-line by the public authorities. All the anomalies encountered are checked on the ground and, if the presence of waste rock is confirmed, an assessment of the added dose is calculated on the basis of generic scenarios chosen according to the current usage of the site.

As the helicopter-borne checks are not absolutely exhaustive, consultation of all stakeholders was organised locally, in particular through the registries in the town halls concerned, during the course of 2014. This consultation should help complete the survey carried out by Areva. It is important that the actions are carried out in complete transparency with maximum involvement of the local stakeholders. They are the first concerned and they remember what use was made of the waste rock in their environment. The information and consultation process shall thus be continued and Areva shall demonstrate whether or not the comments made by the local players on the survey maps are taken into account.

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[132] Regulation value stipulated in the Public Health Code for assessing the compatibility of the observed usages with the observed contamination. It should be noted that it also corresponds to the order of magnitude of exposure of natural origin, excluding radon, which mainly results from exposure to radiation of telluric and cosmic origin.

[133] The report submitted by Areva is available on the websites of ASN and the Ministry responsible for energy:

- http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015 ;
- http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

For the areas with the highest potential consequences (added dose in excess of 0.6 mSv per year), Areva transmitted files of the work to be done to deal with the situation. The work will be carried out in 2015 and 2016.

Finally, to take account of the discovery in the Limousin region of very high radon concentrations in a house built on mining residues, an additional action plan was requested from Areva in a letter from the Minister for the Environment, dated 7th May 2014. Experience feedback shows that the primary health impact from the reuse of uranium-bearing waste rock is caused by radon when the waste rock is located underneath enclosed spaces (dwellings, companies, etc.) and in even higher proportions when dealing with processing residues. It should however be noted that although the reutilisation of waste rock outside the mining sites was not prohibited at the time the uranium mines were being worked, the presence of ore processing residues outside the mining sites and dedicated disposal areas must be managed so that these materials can be transferred to sites authorised to accept them.

This action plan supplementing the instruction of 8th August 2013 consists in conducting a systematic radon diagnosis in living areas in the vicinity of waste rock. The "radon" diagnostic of nearly 600 living spaces close to mining waste rock was initiated at the end of 2014. The results will be known during the course of 2015 and early 2016. The necessary work will be carried out as of 2016.

Waste rock inventory

R13 – Areva will make regular progress briefings to the members of the PNGMDR working group and will submit a report on the steps taken carrying out this inventory, more particularly specifying:
- **how the comments received during the consultation with the public and the stakeholders were taken into account,**
- **a summary of how the various cases in which uranium mining waste rock is present are dealt with,**
- **the outlets which will or have received uranium mining waste rock,**
- **the implementation of the action plan defined in the supplementary instruction of 4th April 2014.**

This report is required before 31st December 2017.
Areva must finalise the steps to deal with mining waste rock before 31st December 2019.

I3 – Degree of progress of steps to deal with mining waste rock (number of "sites" dealt with as compared with the number of sites identified as needing to be dealt with).

3.3 Management of waste containing high levels of natural radioactivity (NORM)

Waste with high levels of naturally occurring radioactivity[134] is generated by the utilisation or transformation of raw materials naturally rich in natural radionuclides (NORM) but which are not used for their radioactive properties. These are low level, long-lived, or even very low level type waste.

Depending on their radiological characteristics, the waste with high levels of natural radioactivity are either managed in-situ, or reutilised, or taken away to conventional waste disposal facilities (four installations are authorised to receive it) or to Andra's dedicated radioactive waste disposal centres.

The management of waste with high levels of natural radioactivity will be profoundly modified by the transposition of the provisions of Council Directive 2013/59/Euratom of 5th December 2013 setting the basic standards for health protection against the hazards arising from exposure to ionising radiation, scheduled for no later than 6th February 2018.

3.3.1 Context and issues

Waste with high levels of naturally occurring radioactivity is generated by the utilisation or transformation of raw materials naturally rich in natural radionuclides (NORM[135]) but which are not used for their radioactive properties. Their radioactivity is due to the presence of natural radionuclides, such as potassium 40, radionuclides of the uranium 238, uranium 235 or thorium 232 family. These radionuclides may be concentrated in the waste by transformation processes. The many activity sectors generating this type of waste and the numerous establishments concerned explain the uncertainty that still surrounds the assessments of the quantities of waste produced and the radiological activity of some of them.

Since the Order of 25th May 2005 concerning professional activities utilising raw materials naturally containing radionuclides not used for their radioactive properties, waste with high levels of natural radioactivity has been subject to specific management methods as presented in the next section (legacy management of these waste is presented in Chapter 3.1). This order draws up a list of the activities liable to generate this type of waste. This waste falls into the following categories:

- very low level waste (for example: foundry sand waste, waste from zirconium-based refractory materials, notably used in the glass-making industry, etc.);
- low level, long-lived waste (for example: certain waste from the processing of monazite, the manufacture of zirconium sponges or the decommissioning of industrial facilities, for example those used to produce phosphoric acid, process titanium dioxide or process zircon flour).

3.3.2 Management of waste containing high levels of natural radioactivity

Depending on their radiological characteristics, the waste with high levels of natural radioactivity are either managed in-situ, or reutilised, or taken away to conventional waste disposal facilities (four

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[134] Formerly referred to a technologically enhanced naturally occurring radioactive materials (TENORM)

[135] Naturally Occurring Radioactive Materials.

installations are authorised to receive them) or to Andra's dedicated radioactive waste disposal centres.

3.3.2.1 Reuse of waste with high levels of natural radioactivity

Certain waste with high levels of natural radioactivity can be reused owing to its physico-chemical properties, in particular for use in the manufacture of building materials. This is particularly the case with coal combustion ashes from thermal power plants, which have binding properties of interest for certain cements.

A study concerning the radioactivity added by the presence of ash was carried out by the hydraulic binders industry technical association in July 2010. According to this estimation, the addition of ashes leads to a slight increase in the radiological activity by comparison with the natural radioactivity already present in the components of the concrete (sand, gravel, limestone, basalt, granite). This varies widely and is heavily influenced by the origin of the components of the concrete.

3.3.2.2 Disposal of waste with high levels of natural radioactivity in "conventional" waste disposal facilities

The regulations make provision for the possibility of disposing of waste with high levels of natural radioactivity in disposal facilities for hazardous waste (ISDD), for non-hazardous waste (ISDnD) or for inert waste (ISDI).

The order of 25th May 2005 concerning professional activities involving raw materials naturally containing radionuclides not used for their radioactive properties and the circular of 25th July 2006 concerning the conditions for acceptance of reinforced or concentrated natural radioactivity (TENORM) waste in waste disposal centres, offer a strict framework for the management of this waste.

The circular of 25th July 2006 is not automatically binding on the licensees concerned but it does urge the Prefects to reinforce the operational requirements applicable to the facilities receiving or wishing to receive this type of waste. The circular thus stipulates that a specific assessment, supplementing the initial impact assessment, must be transmitted to the Prefect. This study aims to prove that the disposal of waste with high levels of natural radioactivity does not jeopardise the protection of the interests mentioned in Article 511-1 of the Environment Code, particularly from the radiation protection standpoint, for both the operating personnel and the neighbouring population, including over the long term. It must be produced in reference to a technical guide published in 2006[136] by the Ministry responsible for the environment and by IRSN.

This circular also specifies the procedures applicable to the licensee for the acceptance and control of waste in waste disposal facilities, the conditions for monitoring the radiological impact on the environment of accepting this waste and the procedures for information about the inspection of classified installations by means of an annual operating report. This report is presented to the local monitoring committees (CSS, formerly CLIS) for the disposal facilities and, as applicable, to the Departmental Council for the Environment and for Health and Technological Risks (CODERST).

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[136] This guide is available for consultation on the IRSN website: http://www.irsn.fr, Accueil > Nos avis et rapports d'expertise > Rapports d'expertise > Surveillance de l'environnement.

Finally, this circular also recalls that in accordance with the polluter-pays principle, any producer of waste is required to provide a technical justification of the validity of the management solution for its waste. It is pursuant to this principle that it requests the performance of a study for each batch of waste to be managed, in order to confirm its acceptability in the destination facilities.

At the end of 2011, a review of the facilities accepting these waste was carried out by the Ministry for the Environment on the basis of the declarations by the Regional Directorates for the Environment, Planning and Housing (DREAL). Only two disposal facilities were identified as authorised to receive these waste, they are the hazardous waste disposal facilities in:

- Villeparisis in the Ile-de-France region, licensed until 31st December 2020, for an annual capacity of 250,000 t/year;
- Bellegarde in the Languedoc-Roussillon region, licensed until 4th February 2029, for an annual capacity of 250,000 t/year until 2018 and 105,000 t/year thereafter.

Two other facilities not identified in the first report are also authorised to take these waste, but in smaller quantities. These facilities also performed assessments enabling them to receive waste with high levels of natural radioactivity, in accordance with the circular of 25th July 2006. They are:

- Champteussé-sur-Baconne in the Pays de la Loire region, licensed until 2049, for an annual capacity of 55,000 t/year;
- Argences in Basse-Normandie, licensed until 2023, for an annual capacity of 30,000 t/year.

The operational experience feedback from the Bellegarde and Villeparisis facilities for the time being shows that there is no contamination of the groundwater linked to the presence of these waste. Oversight of the acceptance of waste containing high levels of natural radioactivity in these centres has been reinforced by orders of the Prefect imposing particular requirements relative to:

- the implementation of an extended prior acceptance procedure (identification of the naturally occurring radionuclides, evaluation of the cumulative doses over one year);
- radiological monitoring (measurement of naturally occurring and artificial radionuclides in the groundwater, leachates and sludges from leachate ponds;
- monitoring of air quality (activity concentration of dust in the air);
- the monitoring of personnel exposure (Labour Code).

The quantities of waste with high levels of natural radioactivity received in these facilities are well below their capacity (less than 10% of total capacity). The Villeparisis and Bellegarde facilities in fact received 25,509 tons and 94,680 tons respectively, between 2000 and 2010 (or 10% and 30% respectively of their annual capacity). The Champteussé-sur-Baconne facility received 1,808 tons between 2002 and 2009 (or 3% of its annual capacity) and the Argences facilities received about 1,530 tons between late 2010 and 2011 (or 5% of its annual capacity), which would seem to indicate that there is no risk of a shortage of disposal capacity. However, there is a question over the share of the total stock accepted by these four authorised facilities. Not all the industrial firms liable to produce waste with high levels of natural radioactivity are actually customers of these facilities.

The work done by the Ministry aims to increase the degree of involvement by the producers of this type of waste: this led to the ordinance of 17th December 2010 modifying the Environment Code, Article L.541-2 of which specifies the responsibilities of the producers or the owners of the waste and requires that they characterise it (Article L.541-7 of the Environment Code). The purpose of characterisation is to identify the substances contained in the waste and measure the concentration, including when these substances can be the origin of ionising radiation. This provision should help clarify the picture with regard to stocks of waste with high levels of natural radioactivity and improve management of the processing circuits.

In 2015, this characterisation of radioactive substances in waste from industries using raw materials rich in natural radionuclides is not yet actually applied but should be, with the transposition of directive 2013/59/Euratom of 5th December 2013 scheduled for no later than 6th February 2018. The traceability of these waste is therefore not yet exhaustive.

3.3.2.3 Disposal of waste with high levels of natural radioactivity in radioactive waste disposal facilities

Very low level waste with high levels of natural radioactivity which cannot be accepted in conventional waste disposal facilities is placed in the Morvilliers industrial centre for collection, storage and disposal (Cires). The 2015 edition of the National Inventory identifies 2,100 m^3 of waste in this category as at the end of 2013, excluding waste generated by spas, paper mills and biomass combustion, which are not actually surveyed in the National Inventory.

Low level, long-lived waste with high levels of natural radioactivity is incorporated into the low level, long-lived waste management industrial systems being studied by Andra (see Chapter 4.1). The 2015 edition of the National Inventory identifies 21,000 m^3 of waste in this category (excluding waste generated by spas, paper-mills and biomass combustion). Pending the arrival of such a repository, this waste is stored on certain production sites.

3.3.3 Recommendations and outlook

The management of waste with high levels of natural radioactivity will be profoundly modified by the transposition of the provisions of Council Directive 2013/59/Euratom of 5th December 2013 setting the basic standards for health protection against the hazards arising from exposure to ionising radiation. **These changes will be presented to the PNGMDR working group**.

3.4. Management of very short-lived waste

Very short-lived waste, in other words only containing radionuclides with a half-life of less than 100 days, is produced by nuclear medicine units and research laboratories.

It can be managed by means of radioactive decay before being sent to conventional management routes.

This management method requires the construction of appropriate storage facilities.

Waste referred to as very short-lived (VSL) is waste containing radionuclides with a radioactive half-life shorter than 100 days[137]. These waste come primarily from medical activities or research laboratories (e.g.: iodine 131 with a half-life of 8 days, metastable technetium 99 with a half-life of 6 h). It should be noted that this category is not defined for waste produced in BNIs.

The activity of very short-lived waste decays appreciably in a few weeks, or a few months. Its management modes must be appropriate to this characteristic.

This management is based more particularly on sorting, characterisation, appropriate packaging and storage to allow radioactive decay before the waste is sent to conventional waste management routes.

For facilities subject to the Public Health Code, the management modes are regulated by ASN resolution 2008-DC-0095[138] of 29th January 2008 setting out the technical rules to be met by the elimination of effluents and waste contaminated by radionuclides, or liable to have been so contaminated owing to a nuclear activity. This resolution in particular makes provision for the implementation of a contaminated waste management plan comprising the management procedures within the establishment concerned, the identification of the places intended for storage of the contaminated waste and the provisions for ensuring their disposal in the appropriate routes and the associated oversight and monitoring procedures. Very short-lived waste can only be sent to a conventional waste route after a period ten times longer than the half-life of the radionuclide (if several radionuclides are present, then the longest radioactive half-life is considered).

This resolution was the subject of ASN guide n°18[139] concerning the disposal of effluents and waste contaminated by radionuclides, produced in facilities notified or authorised under the Public Health Code. This guide explains the requirements and more specifically the technical measures to be taken for the storage of waste as well as the specific procedures applicable to nuclear medicine departments.

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[137] Or when the decay products of these radionuclides are not themselves radionuclides with a half-life longer than 100 days, but for which the ratio of the half-life of the parent nuclide to that of the daughter nuclide is less than the coefficient 10^{-7}.

[138] Resolution 2008-DC-0095 of 2th January 2008 can be consulted on the ASN website at the following address: www.asn.fr, heading « la réglementation », « bulletin officiel de l'ASN ».

[139] Guide N°18 is available on the ASN website at the following address: www.asn.fr, heading « publication », « guide pour les professionnels ».

For installations classified on environmental protection grounds and using radioactive substances, similar provisions are now set out by the Order of 23rd June 2015[140].

These radioactive decay management methods are not however appropriate for all very short-lived waste. Certain waste in fact present other risks (waste containing infectious products, carcinogens, etc.), which cannot be stored in satisfactory conditions of safety. This waste is generally incinerated as rapidly as possible in order to minimise the risks of biological contamination**. The management modes for very short-lived waste must take account of all the characteristics of the waste in order to determine the mode which is most appropriate.**

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[140] Order of 23rd June 2015 concerning facilities utilising radioactive substances, radioactive waste or solid residues from uranium, thorium or radium ore, subject to authorisation under section 1716, section 1735 and section 2797 of the nomenclature of classified installations.

3.5 VLL waste management

In France, the identification of waste from nuclear installations which does not warrant radiation protection checks (“conventional” waste) is based on several independent and successive lines of defence and more specifically on where the waste was produced within the installation. Unlike in other European countries, this means that no clearance level is used. In this way, all the waste which is contaminated, activated or liable to be so is considered to be radioactive waste and must undergo specific management in a route dedicated to radioactive waste. This is part of the reason for the large-scale production of very low-level (VLL) waste so-called, more particularly from decommissioning operations. Andra thus anticipates the production of 2,200,000 m^3 of VLL waste by the existing installations until they are delicensed.

A disposal facility, located in the industrial centre for collection, storage and disposal (Cires) operated by Andra, has been accepting this type of waste since 2003. At the end of 2014, the total volume emplaced in Cires was about 280,000 m^3, or 43% of the authorised regulation capacity (650,000 m3).

In order to preserve scarce disposal site resources, solutions to reduce the flow of ultimate radioactive waste, such as densification or reuse of certain waste, were studied and the efforts made must be continued. However, the facility should reach full capacity within 20 to 25 years, instead of the 30 years initially anticipated, requiring the construction of another disposal facility or extension of the authorised capacity of the current facility by about 2025.

The 2016-2018 PNGMDR requires that Andra, Areva, CEA and EDF continue their efforts to reduce the production of VLL ultimate radioactive waste through densification and reutilisation. Consolidation of the production forecasts for these waste, especially those created by post-operational clean-out and remediation of installation structures and soils, is also required and constitutes an essential step in determining the future choices for overall optimisation of the sector.
The PNGMDR requires that Andra study the possibility and the conditions for increasing the volume capacity of Cires for the same ground footprint and, provided that these conditions are favourable, that it submit the capacity increase application at least 6 years before the anticipated saturation of this facility.

3.5.1 Context and issues

Very low-level (VLL) waste comes mainly from nuclear facility decommissioning operations. Its specific activity is generally less than 100 Bq/g and it could even be below the detection threshold of certain measuring instruments.
VLL waste mainly consists of inert waste (rubble, earth, sand) and metal waste. The quantity of VLL waste produced as at the end of 2014 was about 450,000 m^3, of which 280,000 m^3 has already been sent for disposal[141].

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[141] The bulk of the waste produced and not disposed of is waiting for transfer to “buffer” storage facilities on the producer sites.

Most countries, especially in Europe, have adopted a clearance policy for these waste on the basis of specific activity thresholds per radionuclide, below which the waste is exempted from any radiation protection constraints and can be managed in routes intended for non-radioactive waste. The possibility of implementing such thresholds was confirmed by directive Euratom 2013/59 of 5th December 2013 setting out the basic standards for health protection against the hazards arising from exposure to ionising radiation.

In France, the regulations make no provision for clearance exemption of VLL waste, except in the case of a specific waiver. For BNIs, this involves the regulatory requirement (Order of 7th February 2012 setting out general rules for BNIs and the ASN resolution of 21st April 2015[142]) to determine "waste zoning" for identification of the areas in which the waste produced is contaminated or activated, or liable to be so (known as "areas for possible production of nuclear waste" - ZppDN). The waste produced in these areas must be managed as if it were radioactive [143] and is subject to specific, reinforced management. It must be processed in routes authorised to manage radioactive waste. This management principle is one of the reasons for the increased production of very low level waste so-called. However, this principle strengthens the robustness of radioactive waste oversight, allows the waste to be traced and also makes for simpler implementation in the field, enabling it to be adopted by everyone involved in the process.

Some categories of waste, more specifically liquid waste and certain solid waste, are incinerated, but most VLL waste is today considered to be ultimate radioactive waste and sent to a dedicated disposal facility, the industrial centre for collection, storage and disposal (Cires) in Morvilliers. This VLL waste repository operated by Andra in the Aube département has been operational since the summer of 2003. With a disposal capacity of 650,000 m^3 of waste, it initially corresponded to the requirement identified for a period of thirty years. Waste production estimates indicate requirements higher than those on which the initial waste inventory for this repository was based. New disposal capacity will be needed.

Efforts must be made to optimise VLL waste management, in order to comply with the general waste management principles defined in Chapters I and II of Title IV of Book V of the Environment Code, which is based on a pyramid of waste management modes, with priority given to the prevention and reduction at source of the volume and harmfulness of the waste, then reutilisation, recycling, reuse and finally, disposal. Alternatives to waste disposal in Cires are therefore analysed below.

3.5.2 VLL waste inventory

According to the data in the National Inventory of radioactive materials and waste published by Andra in 2015, the quantity of VLL waste produced as at the end of 2013 was about 440,000 m^3. The production forecasts made by the licensees indicate total VLL waste production at about 650,000 m^3 in 2020, 1,100,000 m^3 in 2030 and 2,200,000 m^3 by the end of the service life of the facilities.

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[142] ASN resolution 2015-DC-0508 of 21st April 2015 concerning the study of waste management and the inventory of waste produced in the BNIs.

[143] Notwithstanding this provision, the waste produced in zones with the possible production of nuclear waste can be managed as non-radioactive waste if it can be demonstrated that in no way and at no time could it have been contaminated or activated.

The forecast volume of VLL waste from operation and then decommissioning of the existing nuclear facilities is a key parameter in identifying future requirements for VLL waste management facilities, in particular the associated capacity.

The above-mentioned estimates still comprise uncertainties linked to post-operational clean-out of structures and management of soils polluted by radioactive or chemical substances, which will take place at the end of the decommissioning work. These uncertainties are more specifically linked, on the one hand to insufficient data on the initial state and, on the other, to problems with characterising any pollution present under the buildings in use. In this respect, in the 17th July 2015 version of its guide n° 6 concerning the final shutdown and decommissioning of BNIs, ASN presented its doctrine concerning the state to be reached at the end of decommissioning in order to allow a BNI to be delicensed, if necessary after implementation of institutional controls.

R1 – The forecast estimates of VLL waste production to be produced in the next editions of the National Inventory of radioactive materials and waste shall rely on the hypothesis of post-operational clean-out allowing delicensing. The waste linked to soil remediation will need to be clearly identified as of the 2021 edition of the National Inventory of radioactive materials and waste.

R2 – Areva, CEA and EDF shall submit a study, by 30th June 2018, presenting:
- **on the one hand, the methodology and uncertainties associated with the forecast estimates of VLL waste production. These uncertainties shall be justified and the licensees shall take steps to reduce them;**
- **on the other, decommissioning case studies for each licensee, evaluating the volumes of VLL waste produced according to several post-operational clean-out scenarios. The level of uncertainty associated with these case studies will be evaluated.**

3.5.3 Limiting waste production

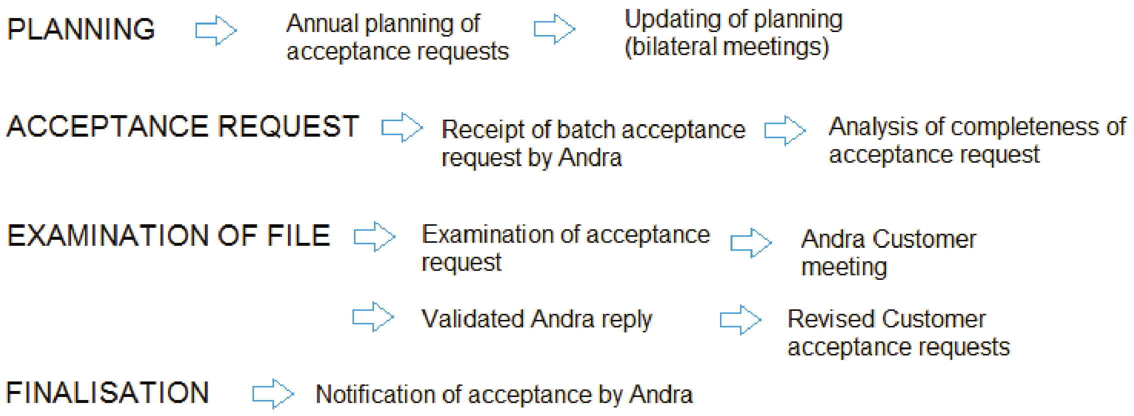
Chapter 1.2 of part 1 of this PNGMDR details the management principles for radioactive waste and in particular the principle of limitation at source of radioactive waste production. This principle is particularly important for management of VLL waste. The design and organisation put into place for operation of nuclear facilities will have a considerable impact on the production of VLL waste during decommissioning, more specifically owing to the contamination of soils and structures.

R3 – By the end of 2020, Areva, CEA and EDF will define the lessons learned from implementation of waste zoning in their facilities, in order to identify best practices in terms of design, construction and operation, such as to optimise waste zoning in the facilities and make it easier to delicense the ZppDN during decommissioning.

3.5.4 Management methods used by the producers

The VLL route has been operational since mid-2003. Together with Andra, Areva, CEA and EDF have developed the means of optimising the route, both by densification of the individual packages delivered and by increasing emplacement density in the disposal facilities (ground footprint). The process linked to acceptance of the waste was entirely revised in 2014 to ensure more fluid exchanges and facilitate the examination of the files for VLL waste acceptance in the Cires. This acceptance process is summarised in the following flowchart.

Flowchart of acceptance process for VLL waste



The VLL waste is packaged in finished packages ready for shipment to the Cires, in accordance with the requirements defined in Andra's acceptance specifications. These acceptance specifications are revised according to a calendar defined between Andra and the nuclear licensees. These revisions take account of changes to the regulations and incorporate operating experience feedback from Cires and optimisation proposals from the nuclear licensees.

The waste can be packaged on the actual production sites or in dedicated facilities which include processing (volume reduction, stabilisation if necessary, decontamination, etc.). The radiological characterisation of these waste is carried out: in-situ prior to disassembly or when making up the packages (directly on the waste or materials before final packaging) or on the finished package. Each characterisation method (surface inspections, dose rate measurements, spectrometry, etc.) is appropriate to the radionuclides present and the type of waste.

Computer tools have been developed by each licensee and help guarantee the traceability of the waste, from origin to acceptance in Cires. Work to share these tools was started in 2015. This joint work by CEA, EDF, Areva and Andra will take several years and its aim is to identify the various tools used and the requirements and constraints of each one and to define the needs and the means that could be developed (creation of gateways between tools, etc.).

R4 – The producers of VLL waste must take all steps to remove their waste to facilities authorised to manage it, primarily Cires, taking account of any radiation protection, transport and disposal facility operating constraints, plus the technical-economic conditions.

I1 – Indicators – Licensee monitoring of the annual volume of VLL waste taken from the production sites, by comparison with the volume of VLL waste produced.

I2 – Licensee monitoring of the quantities of VLL waste (excluding legacy VLL waste) stored on the production site for more than 24 months.

3.5.5 Reutilisation

With a view to making the transition to an economy which more particularly aims to preserve resources and improve how efficiently they are used, preference must be given to recycling the reusable substances extracted from the waste. This practice is common for non-radioactive waste, especially metal waste.

With regard to the recycling of waste from nuclear facilities, this is a practice used by the member States of the European Union who so wish, using "clearance levels" enabling them to be used under certain conditions for conventional applications, pursuant to the Directive of 5th December 2013[144]. The clearance levels for these materials were previously regulated by Directive 96/29 and the corresponding technical recommendations[145]. Three melting facilities for radioactive metal waste, for the purposes of recycling metal materials in the nuclear or conventional sectors are thus operational in Europe (these facilities are operated by Socodei in France with recycling only in the nuclear sector, Studsvik in Sweden and Siempelkamp in Germany).

In France, the reutilisation conditions are regulated by the Public Health Code. Barring waivers, its Article R. 1333-3 prohibits the use of materials or waste from nuclear activities, liable to be contaminated by radionuclides, in the manufacture of consumer goods and building materials. Recycling options[146] are thus for the time being limited to the nuclear sector in areas identified as potentially containing waste that is contaminated, or activated, or liable to be so.

In accordance with the principles set out in Articles L. 542-1 and following of the Environment Code, industrial recycling technologies for radioactive waste have however been developed by Areva, CEA or EDF, sometimes via subsidiaries of these companies. They are described in section 3.6.3 of this Plan. They concern low level waste and, to a lesser extent, very low level waste. However, the volumes recycled in these facilities are marginal.

One of the focal points for work in the 2013-2015 PNGMDR thus concerned the reuse of metal materials and rubble, in particular those with very low level activity, in strict compliance with the health protection and safety of individuals and the environment. EDF, Areva, CEA and Andra thus submitted studies on possible avenues for the development of these routes, presented in

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[144] Council directive 2013/59/Euratom of 5th December 2013 setting out the basic standards for health protection against the dangers arising from exposure to ionising radiation and abrogating Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom

[145] The technical recommendations published by the European Commission are available on the website: http://ec.europa.eu/atoz_en.htm, heading « energy », « nuclear energy », « radiation protection». This concerns the following reports in particular:

- Radiation Protection 89 – recycling of metals, which proposes clearance levels for the recycling of metals from the decommissioning of nuclear facilities;
- Radiation Protection 122 which proposes unconditional clearance levels for solid materials;
- Radiation Protection 113, which proposes mass and surface clearance levels for the demolition or reutilisation of buildings.

[146] The reasons for this management choice are explained in the 2007-2009 edition of the PNGMDR.

section 3.5.5.1. A pluralistic working group comprising representatives of the licensees, Andra, the Ministry for the Environment, Energy and the Sea, the safety regulators (ASN and ASND), CLI members, representatives of industry and French and foreign experts was set up to examine the potential conditions for the reuse of VLL waste[147]. The conclusions of this working group are presented in section 3.5.5.3.

3.5.5.1 Nuclear licensee proposals concerning the reuse of VLL rubble

Areva, CEA and EDF assessed the forecast inventory of rubble expected to be produced. They estimate that about 240,000 t of rubble will be produced between 2012 and 2033, of which 64,000 t could be reused.

The use of rubble as infill material at the Cires

The project studied by Andra consists in using crushed VLL concrete rubble in the Cires disposal vaults to replace the sandy materials ("untreated gravel") used to fill in the voids within a package, between packages or as a subgrade layer between two disposal levels and for the final shape of the vault once filled. Andra currently uses 11,000 t of these materials to build a vault (given that one vault is filled every year).

In order to enable this reutilisation while guaranteeing that the safety and radiation protection objectives are met for the personnel and to prevent any risk of dispersal of radioactive substances outside the disposal vaults, Andra identified applicable particle size criteria for the crushed materials, specific activity limits for the concrete and particular operating measures.

Andra thus estimates that 1,800 m^3 per year of crushed concrete could be reused, enabling 8% extra waste to be emplaced per vault in this form. A study is in progress to clarify these values and verify whether this management mode is economically pertinent. Andra aims to issue its conclusions for the end of 2016.

R5 - No later than 31st March 2017, Andra shall complete its study of the use of very low level rubble as infill material for the voids in the Cires vaults.

R6 – In order to optimise the use of Cires, barring disqualifying conditions concerning protection of the interests mentioned in Article L. 511-1 of the Environment Code, Andra shall deploy this solution for reuse of very low level rubble operationally before 31st December 2018, provided that this is feasible in economically acceptable conditions, with the economic analysis being required to include the scarcity of disposal resources.

3.5.5.2 Nuclear licensee proposals concerning the reuse of metal waste

Areva, CEA and EDF produced an inventory of forecast VLL metal waste expected to be produced by 2070. They estimate that about 900,000 t of potentially reusable waste would be produced over this period. This inventory, for which a detailed chart of the production forecasts is given below, can be broken down as follows: about 150,000 t of steel from the diffusers in the George Besse 1

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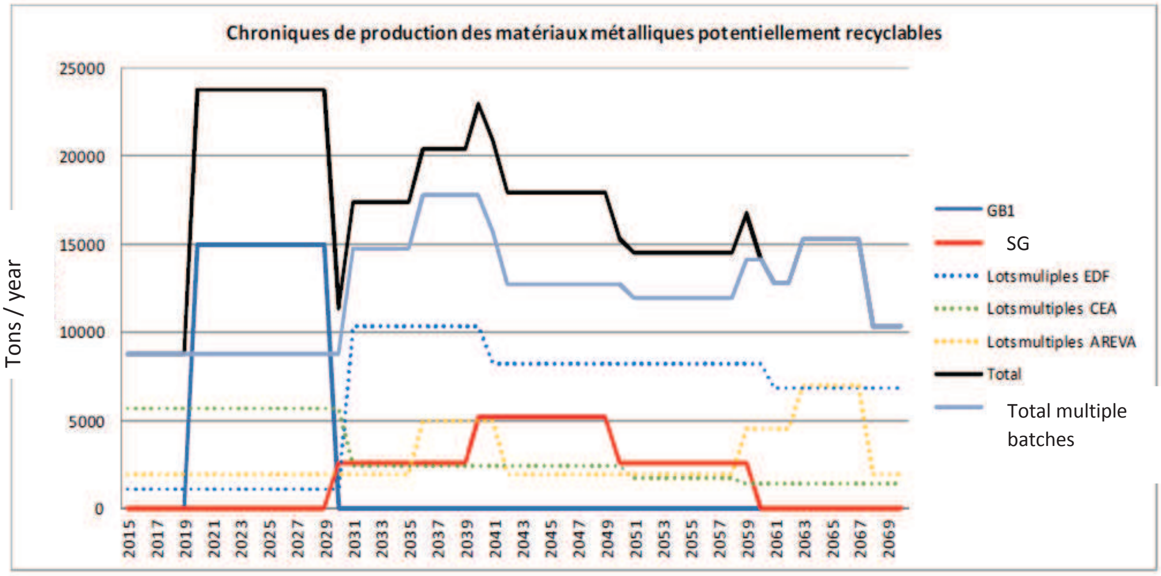
[147] The report submitted by the pluralistic working group pursuant to the 2013-2015 PNGMDR is available on the websites of ASN and the Ministry responsible for energy:

- http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015 ;
- http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

(GB1) plant, 100,000 t from the reusable part of the steam generators (SG) from the EDF NPP fleet and 650,000 t of assorted metals for which the nuclear licensees consider that a significant part is free of all activity.



Production charts for potentially recyclable metal materials
Source: AREVA, CEA, EDF report submitted at end 2014 for the 2013-2015 PNGMDR on evaluating the definition of a route for the reuse of metal materials from the decommissioning of nuclear facilities

An initial study on the possible modes of reusing VLL materials was submitted in 2012 by Andra, Areva, CEA and EDF. The report concluded that a dedicated foundry appeared to be the most appropriate but that the industrial feasibility of implementing it in a recycling route in the form of cast iron containers for low and intermediate level, short-lived waste (LLW/ILW-SL) could not be demonstrated, with economic break-even being uncertain and fragile.

The reports submitted by Areva, CEA and EDF and by Andra for the 2013-2015 PNGMDR[148] propose the industrial methods necessary for the feasibility of a VLL materials recycling solution.

The licensees stress the point that recycling is made difficult in France by the absence of outlets other than the areas with possible production of nuclear waste within the nuclear facilities, the complexity of the licensing process to develop reutilisation solutions and the competitiveness of VLL waste disposal. To encourage it, industry considers that the regulations should be proportionate to the risks presented by certain waste for which no radioactivity has been detected. According to the licensees, the implementation of differentiated management modes based on activity thresholds would be justified by an approach proportionate to the health and environmental implications. The licensees claim that this approach, which would be an extension of the principles in force for industrial and hazardous waste to waste liable to be radioactive, would also encourage the reuse of certain non-ferrous and semi-precious materials present in small quantities, using the existing facilities.

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[148] These reports are available on the websites of ASN and the Ministry responsible for energy:
- http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015 ;
- http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

Industrial solutions for processing / recycling metals exist in France and in Europe and projects are currently being examined, in particular for large homogeneous batches such as the steam generators (SG) in the EDF NPP fleet and the diffusers from the GB1 plant. The nuclear licensees thus estimate that the particular case of GB1 steels could be one of the pilots for setting up a reutilisation route. They propose a solution comprising a dedicated foundry, which would be an installation classified on environmental protection grounds (ICPE), exclusively handling metal waste from BNIs, in batches. These could then be transformed into products in a dedicated or temporarily dedicated conventional facility.

According to the nuclear licensees, decontamination, more specifically through melting, should in certain cases make it possible to reach activity levels with no further radiation protection implications. The decontamination properties of melting, in particular for the alpha emitting elements (uranium for example) are confirmed by operating experience feedback from European facilities.

The outlets studied for reutilisation of these materials in the nuclear industry, in the form of shielded containers[149], represent considerable potential of 80,000 to 140,000 t, although significantly lower than the inventory of 900,000 t of VLL metal materials identified by the licensees over the period studied. The licensees consider that other solutions must be identified in order to envisage the viability of an industrial route offering possibilities for use outside areas of potential nuclear waste production.

The action plan proposed by the producers consists in:

- *"continuing and finalising studies of industrial solutions envisaged primarily for the two homogeneous batches (GB1 and SG) and developing possible synergies and pooling;*
- *characterising all possible outlets for reutilisation in accordance with the regulations in force;*
- *highlighting for the public authorities and stakeholders the benefits of regulatory changes, for development of reutilisation routes, in particular for all miscellaneous batches, which represent most of the volume, for which no industrial solutions have as yet been identified.*"

3.5.5.3 Identification of conditions favourable to reutilisation

A pluralistic working group was set up by the DGEC and ASN within the framework of the 2013-2015 PNGMDR in order to identify the conditions for the reutilisation and recycling of certain substances. Based on operating experience feedback from reutilisation routes and on the analysis of the studies conducted by Andra, Areva, CEA and EDF, the working group formulated recommendations and proposed avenues for work concerning:

- technical matters, more specifically the identification of types of materials and processes enabling favourable physico-chemical and radiological characteristics to be obtained;
- reutilisation routes, with identification of facilities appropriate to the health, environmental, societal and radiation protection implications of the types of substances at each step in processing, and the corresponding traceability procedures;
- the foreseeable outlets, proposing a ranking system for them in order to guarantee the traceability of the reused materials to the extent possible;
- analysis of management options, with an overall “lifecycle” type approach, which should be able to compare the drawbacks and benefits of the various conceivable solutions;
- the procedures for information and participation of the stakeholders, both locally and nationally;

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[149] Their acceptance for disposal should be demonstrated in the light of their potential impact on the operating conditions and long-term safety of the repository.

- the content of the waiver files required by the regulations in the case of reutilisation outside the nuclear industry.

The working group thus recommends that:

- the study of reutilisation solutions be primarily focused on large homogeneous batches with known and verifiable characteristics, making it possible to envisage developing a process on an industrial scale, ensure reliable controls at various steps in the process and provide guarantees as to the quality of the finished products;
- the performance of the processing processes be substantiated on the basis of several independent, successive lines of defence, more particularly including full knowledge of the materials and processes and the definition of a programme of checks and measurements. At this stage, melting is an unavoidable step in the reutilisation of metal materials, as it ensures reliable characterisation and produces homogeneous batches. In certain cases, and by means of decontamination, it enables characteristics favourable to reutilisation to be obtained for metal materials;
- the processing solutions comprise facilities handling only items from nuclear facilities, to the extent possible. If a processing step has to be performed in a facility also handling conventional materials, the working group recommends that:
  - special measures be defined, in particular concerning materials traceability, secondary waste, scrap, discharges, etc.;
  - radiological criteria be defined and checked in order to minimise the constraints associated with the management of materials from nuclear facilities;
  - the potential impact of processing materials from nuclear facilities on the activities of the industrial partner be assessed and checked;
  - the staff have an adequate occupational health and safety culture;
- the procedures for the traceability of materials, waste, scrap, discards, by-products, etc. be determined for each step on the reutilisation route. The conditions whereby the substances are exempted from traceability shall be specified as and when necessary;
- reutilisation outside areas in which the waste produced is liable to be contaminated or activated should only be envisaged for materials which, when used, would not compromise health and environmental protection, taking account of the worst case scenarios, including a loss of traceability;
- for each outlet identified, the quantities of substances liable to be reused and the economic model, are evaluated in order to verify the pertinence of the planned route;
- the outlet selection criteria include the guarantee of long-term traceability of the products;
- the greatest transparency is adopted in the study and then deployment of the processing and reutilisation routes:
  - within the companies (including subcontractors): information and participation of the staff, the personnel representative bodies, the trades unions, occupational physician, etc.;
  - locally, in particular on the processing or transformation site (and the reutilisation site if possible) and, as applicable, the site from which the materials originate: information of bodies such as the local information committees, information commissions, site monitoring commissions, etc.;
  - at the national level (PNGMDR working group, ANCCLI, HCTISN);
- in the case of outlets outside the nuclear industry, appropriate information procedures shall be put into place.

With regard to the regulatory procedure, the working group considers that:

- the provisions of Article R. 1333-4 of the Public Health Code could be implemented to allow the use of materials liable to be contaminated by radioactive substances in construction materials and consumer goods, but that the procedure must be adapted;
- the file submitted pursuant to the Order of 5th May 2009 should be based on the following:
  - present a health and environment impact assessment;
  - present the quantities of materials concerned;
  - incorporate an overall review including a lifecycle analysis;
  - specify the conditions for traceability and radiation protection and, as applicable, the time at which these are no longer required;
  - public information and participation.

3.5.5.4 Reutilisation prospects

ASN considers that the management of VLL radioactive waste must remain based on the place of origin of the waste and must guarantee its traceability, by means of specific routes, from production to disposal, and that this principle is incompatible with the generalised deployment of "clearance levels".

The conclusions of the working group presented in section 3.5.5.3 should constitute a working basis for continued studies into the possibilities of reutilisation carried out by the producers of VLL waste, but without the decision to actually implement this route being taken at this stage. In any case, this implementation could only be envisaged after the regulation steps stipulated in the Public Health Code, more particularly the organisation of a number of mandatory consultations.

R7 – The reutilisation capacity for very low level materials within the nuclear sector[150] will need to be fully exploited[151] before resorting to any other solutions.

R8 – On the basis of the recommendations of the working group, summarised in section 3.5.5.3 and of recommendation R7, Areva and EDF must submit a file before mid-2018 which on the one hand presents the technical and safety options[152] for a facility to reprocess their large homogenous batches of very low level metal materials (reusable part of the SGs and GB1 diffusers) and, on the other, describes the corresponding management routes.

This file shall also give a calendar for commissioning of the facility.

3.5.6 Incineration

Incineration is a mature and industrially proven technology, based on processes employed for decades to process conventional waste. Its benefits are a significant reduction in the volume of the waste prior to disposal and the ability to process a broad spectrum of waste: solid waste, organic liquid waste and aqueous liquid waste. The final waste is stable, chemically inert, non-dispersible

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[150] The nuclear sector corresponds to facilities for which a waste zoning plan is required and identifies the zones which could contain waste that is contaminated or activated, or liable to be so, in order to guarantee the traceability of the resulting waste, from production up to disposal.

[151] This analysis must be performed taking account of the production calendars for these materials and the consumption in the nuclear sector. It shall take account of the new facilities if the calendars are compatible.

[152] Corresponding to a preliminary design stage.

and packaged in a format suitable for disposal. The incineration solution at Centraco is more particularly used for low and intermediate level waste, as described in section 3.6.4 of this plan.

For very low level waste, this solution is little used owing to its cost. Liquid or putrescible organic waste is incinerated, but Andra estimates that nearly 4,000 m^3 of incinerable waste are sent directly to disposal every year.

R9 – Together with Socodei and the producers of radioactive waste, Andra will for each type of incinerable VLL waste submit a study before the end of 2017 comparing incineration/disposal of residues with direct disposal, in terms of individual health, the environment and safety. This analysis will more particularly take account of the radioactive and chemical discharges resulting from the incineration process.
The 2018-2021 PNGMDR will then be able to rule on whether or not incineration is the best available technique (BAT) for certain types of VLL waste.

3.5.7 VLL waste disposal on-site or close to the production sites

The disposal of certain radioactive waste on or near the sites, more particularly those undergoing decommissioning, which produce large quantities of VLL waste, could be envisaged in order to limit radioactive waste transportation in terms of distance and volume, in accordance with the principles set out in Article L. 541-1 of the Environment Code. It would concern certain VLL waste for which the specific activity and physico-chemical properties would allow regional management methods.

On this subject, ASN considers that the possibility of creating local disposal facilities appropriate to certain types of VLL waste should be examined in conditions complying with protection of individual health, safety and the environment, at least equivalent to those of Cires[153].

Areva, CEA and EDF consider that the benefits of disposal on-site are to be assessed, taking account of all environmental, economic and industrial impacts (including industrial site reutilisation projects). They consider that particular attention must be given to the design and sizing of the projects with respect to the safety constraints that must be adapted to the radiological characteristics, but which must also take account of the industrial viability of such a disposal facility and of these impacts on the operation of the Cires and the VLL industrial system in general. The approach shall more specifically be based on:

- analysis of the consequences concerning the footprint of these projects on the industrial sites,
- the necessary adaptation of the regulatory framework (design, operation, monitoring), in particular based on the definition of types and characteristics of the waste eligible for this type of disposal.

R10 – Areva, CEA and EDF shall set up an iterative approach with Andra in order to reach a conclusion, no later than 30th June 2020, on the feasibility of creating disposal facilities

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[153] ASN opinion 2016-AV-0258 of 18th February 2016 concerning the management of VLLW and ILW-SL waste is available on the website: http://www.asn.fr, heading « les actions de l'ASN », « la réglementation », « bulletin officiel de l'ASN », « avis de l'ASN ».

on or close to their respective sites, suitable for certain types of VLL waste, the characteristics of which mean that their disposal in dedicated facilities other than Cires could be envisaged, in compliance with the requirements concerning the protection of individual health, safety and the environment, in acceptable technico-economic conditions.

This iterative approach shall rely, on the one hand, on the forecasts by the nuclear licensees of the volumes, specific activity and physico-chemical properties of the types of VLL waste concerned and, on the other, on Andra's definition of the characteristics of the appropriate disposal concepts.

This approach must aim to limit waste shipments in terms of distance and volume, as mentioned in Article L. 541-1 of the Environment Code.

The environmental impact of these management methods shall be the subject of a comparative analysis with the scenario involving transportation to Cires or an equivalent facility.

3.5.8 Waste disposal in the industrial centre for collection, storage and disposal (Cires)

Disposal concept

The disposal of very low level waste is based on the technical concepts used in hazardous industrial waste disposal facilities (ISDD). This involves surface disposal in vaults excavated from clay, with the base modified to collect any water infiltration for the duration of disposal. The waste is thus isolated from the environment by a system comprising:

- an "active barrier" consisting of a polymer membrane surrounding the waste, enabling any leachates to be collected and sent to pits;
- a "passive barrier" consisting of a layer of clay under and along the sides of the disposal vaults, plus a cover - also of clay – over the waste.

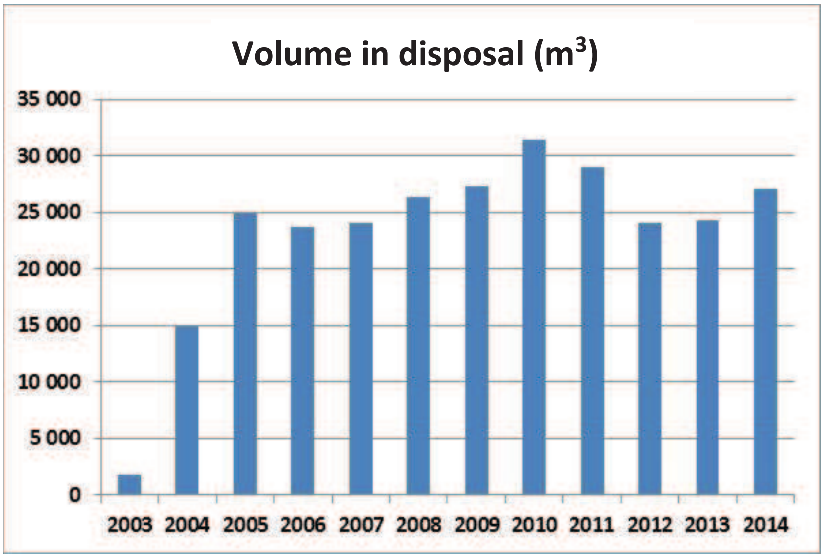
During operation of the centre, when being emplaced, the waste is protected from rain by means of mobile roofs. The long-term containment of radioactive elements and chemical substances will be ensured by the permeability properties of the clay formation.

The experience acquired with the operation of the centre has enabled Andra to optimise the geometry of the disposal vaults, thus improving the use of the disposal space available, that is the ratio between the volume of waste emplaced and the surface area occupied. The length of the vaults was doubled, they were made deeper and their slopes made a little steeper. It would therefore be technically possible in the same footprint to emplace a volume of waste 40% greater than the capacity authorised by the regulations (excluding the optimisations presented in section 3.5.5.2). Andra has also developed new mobile shelters to protect the disposal vaults from the rain; relocating these shelters will be easier and less dependent on the weather, which will reduce any risks of disposal facility unavailability.

Cires can accept packages with non-standard geometries. It was thus possible to emplace four steam generators from Chooz A there without cutting, after on-site decontamination during decommissioning. In order to provide an industrial response to this need, Andra announced that it will be commissioning a dedicated vault for the disposal of outsized packages (large components), more particularly from the decommissioning of nuclear facilities. This vault will be equipped with handling systems suitable for heavy loads.

Volume and radiological capacity of Cires

At the end of 2014, the total volume emplaced was about 280,000 m^3, or 43% of the authorised regulation capacity (650,000 m^3). This volume represents about 290,000 t of waste.



Annual volume of waste disposed of in Cires (Source: Andra)

Management of the radiological capacity of the Cires disposal facility poses no particular problems at the present stage. With respect to the authorisation licenses, the utilisation level is generally below 5%, except for ^{232}Th which, at the end of 2014, was 30% and ^{108m}Ag which is 10%. These values however remain lower than the consumption of volume capacity.

I3 – Monitoring of Cires volume capacity.

I4 – Monitoring of Cires radiological capacity, per radionuclide.

Optimisation of management of waste emplaced in Cires

The density of the radioactive waste packages emplaced in Cires (about 1 t/m^3) is structurally 20 to 30% lower than the initial forecasts. The low density of the waste disposed of is even likely to lead to early saturation of Cires. It is therefore, **necessary to take steps to increase the density of the waste emplaced.**

R11 – Andra and the waste producers shall take steps to increase the density of the waste emplaced in Cires. Progress is expected on each of the routes mentioned in recommendation R12.

The adequacy of the means used (shears, press, etc.) on the main VLL waste production sites shall be demonstrated for the BNIs, in the "waste studies" for these facilities.

R12 – Before mid-2018, Andra together with the VLL waste producers and Socodei, shall therefore produce a study analysing several options, with regard to protection of the interests mentioned in Article L. 511-1 of the Environment Code: densification on the producer sites, improvements to existing equipment or commissioning of new equipment in Cires.

R13 – The producers of VLL metal waste and Socodei, together with Andra, shall before 30th June 2018 submit a technico-economic feasibility study on the melting of VLL metal waste for densification. This study shall include the environmental impacts.

I5 – Monitoring of density of waste disposed of in Cires. [Objective: increased density – objective to be clarified later]

3.5.9 Optimisation of VLL waste management routes

On the basis of the data provided by the producers for the 2015 edition of the National Inventory, the volume capacity of the Cires disposal facility would be saturated in about 2025, earlier than the date of 2030 considered when the facility was designed.

In the light of the forecast time-frames for saturation and the disposal requirements as currently assessed by the producers, an industrial plan for management of VLL waste[154] was defined by Andra and comprises a number of additional management avenues which could be implemented. The avenues considered by Andra in this industrial plan are as follows:

- construction of a second VLL waste repository;
- reuse of certain VLL substances in the nuclear sector (this could concern about 100,000 to 200,000 m^3 depending on the industrial plan);
- reuse of certain VLL substances in the conventional nuclear sector (provided that a waiver is obtained) (this could concern about 300,000 m^3 depending on the industrial plan);
- construction of one or more repositories, possibly on the waste production sites, for “very, very low level" waste (this could concern about 600,000 m^3 depending on the industrial plan);
- significant reduction in the volume of the waste produced (this could concern about 600,000 m^3 depending on the industrial plan);
- implementation of clearance levels (this could concern about 600,000 m^3 depending on the industrial plan);

This forward-looking assessment indicates that regardless of the optimisation of the Cires disposal space carried out, the need to increase the VLL waste disposal capacity cannot be avoided[155], to enable completely safe management of the VLL waste that will be produced between now and the end of decommissioning of the existing facilities and which amounts to more than 1,300,000 m^3 according to the estimates of the 2015 edition of the National Inventory.

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[154] This report is available on the websites of ASN and the Ministry responsible for energy:
- http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015 ;
- http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

[155] The potential figures given per management route do not add up, because the figures for two routes can concern the same initial fraction of waste. For example, a given metal waste can be considered suitable for both “recycling” and “clearance”.

R14 – Andra shall specify the conditions for increasing the volume and radiological capacity of Cires for the same ground footprint and shall confirm that this is possible.

R15 – If this possibility is confirmed, Andra shall submit an application for an increase in the authorised capacity of Cires at least 6 years before the anticipated saturation of this facility. In the event of refusal by the administrative authority, this would give enough time to find a new site.

R16 – By the end of 2020, Andra shall examine the updating of the VLL disposal acceptance criteria for certain waste containing thorium- and uranium-bearing substances, in accordance with the repository's safety objectives.

A second VLL repository will eventually be necessary for disposal of the VLL waste to be produced.

R17 – The safety objectives and the design of this facility shall take account of experience feedback from the design, construction and operation of Cires, the progress made in scientific knowledge, the best available techniques in accordance with the rules applicable to installations classified on environmental protection grounds.

The additional avenues for the management of VLL waste however need to be studied in greater detail, in particular with regard to the improvements they could make to application of the waste management principles defined in chapters I and II of title IV of book V of the Environment Code (hierarchy of waste management modes, prevention and reduction at source of the volume and harmfulness of waste, limitation of transports).

R18 – Together with the waste producers, Andra shall before the end of 2020 submit a revised overall industrial plan for the management of very low level waste, integrating the associated costs for the various scenarios that could be defined. This update includes a proposal for a multi-criteria analysis chart able to demonstrate the pertinence of the choices made for the management of VLL waste, more particularly with regard to the environment.

3.5.10 Radioactive waste transport

The transport of VLL waste has an environmental impact. Efforts must therefore be made to optimise and thus limit transports.

R19 – Areva, CEA, EDF shall, before 31st December 2018, submit a study assessing and identifying means of mitigating the environmental impacts of the transport of VLL waste to the Cires repository, if necessary after processing.

3.6 Management of LLW/ILW-SL waste

"Short-lived" low and intermediate level waste (in which the radioactivity comes mainly from radionuclides with a half-life of less than 31 years) has since 1969 been disposed of in dedicated surface repositories.

The Manche repository received 527,000 m^3 of waste packages between 1969 and 1994. It entered the surveillance phase in 2003. The leaktightness of the facility is based on the installation of a cover, which must be consolidated to ensure its long-term stability (reducing the steepness of the slopes). This will take place over a period of about fifty years. Steps have been taken to ensure that a recorded trace (memory) of the facility and the waste emplaced in it is kept for future generations.

At the end of 2014, the total volume of packages emplaced in the Aube repository (CSA) was about 292,000 m^3, or 29% of the authorised regulation capacity (1,000,000 m3). Efforts made at source to reduce the amount of LLW/ILW-SL waste produced, and the commissioning of a VLL waste repository in Cires, plus the melting and incineration solutions, enabled the lifetime of the repository to be extended.

The 2016-2018 PNGMDR asks that Areva, CEA, EDF and Socodei conduct a study of the means of transport of LLW/ILW-SL waste in order to reduce its environmental impacts It also asks these licensees to submit a preliminary design for a lead processing facility.

3.6.1 Context and issues

Low level and intermediate level short-lived waste (in which the radioactivity comes primarily from radionuclides with a half-life of less than 31 years) is mainly produced during the operation of nuclear facilities (plants, laboratories, NPPs) and more specifically as a result of maintenance work (clothing, tools, filters, etc.). It can also come from post-operational clean-out and decommissioning of such facilities (NPPs in particular). It takes various forms:

- solid, for example tools, gloves, clothing, disassembled parts and components, water or air filters, ion exchange resins, etc.
- liquid, for example decontamination effluents, evaporator concentrates, used solvents, scintillation fluids used for analyses, etc.

Certain LLW/ILW-SL waste is processed by melting or incineration in the Centraco facility operated by Socodei in Marcoule, in order to reduce its quantity and harmfulness. The ultimate radioactive waste is disposed of in two surface repositories: the Manche waste disposal facility (CSM) which has no longer been accepting any waste since 1994 and the Aube waste disposal facility (CSA) which has been in operation since 1992.

The quantity of LLW/ILW-SL waste produced as at the end of 2013 was about 880,000 m^3 and the 2015 edition of the National Inventory evaluates its volume (disposed of and to be produced) at about 1,000,000 m^3 in 2020 and 1,200,000 m^3 in 2030. The CSM can take 527,000 m^3 of waste and the CSA has a capacity of 1,000,000 m^3, so no need for new disposal capacity is envisaged in the short to medium term. However, the National Inventory anticipates a total of 1,900,000 m^3 by the end of the service life of the facilities. The existing repositories would not therefore be able to take all the waste produced by the operation and decommissioning of the current facilities.

In any case, management of the LLW/ILW-SL waste must be optimised in order to minimise its production and reduce the quantity and harmfulness of the ultimate radioactive waste. Furthermore, avenues for the overall optimisation of radioactive waste management are dependent on changes to the specifications for acceptance of certain waste in the CSA. This possibility shall therefore be examined by Andra in compliance with protection of the interests mentioned in Article L. 593-1 of the Environment Code, nuclear safety in particular.

3.6.2 Management methods used by the producers

LLW/ILW-SL type ultimate radioactive waste is intended for Andra's Aube repository. With the aim of preserving disposal space, steps are taken (sorting, processing, etc.) to reduce the volume of ultimate radioactive waste. The progress made in the design and operation of nuclear facilities, fuel management, the operation of nuclear facilities and the measures to reduce waste at source have led to a reduction in the volume of these waste. For example, the annual volume of LLW/ILW-SL waste packaged per reactor in service has fallen from 360 m^3 in 1985 to an average of 100 m^3 since 1996. The nuclear licensees have also to the extent possible initiated measures to minimise the volume of waste (undergoing packaging or packaged) stored on their sites, by adopting a policy of immediate removal.

So that it can be disposed of, LLW/ILW-SL type waste must be packaged into a solid, non-dispersible block which contains no water liable to be released. This packaging must comply with the repository's acceptance specifications[156] and the producers must obtain approval from Andra confirming the conformity of the packages with the disposal acceptance specifications prior to delivery of the packages. A draft ASN resolution is being prepared to clarify the conditions in which waste packages are to be produced and may be received in the existing disposal facilities.

The packages must guarantee waste containment appropriate to its radiological characteristics. This containment is by means of blockage or encapsulation of the waste, if necessary after prior processing, using specific materials appropriate to the physico-chemical characteristics of the waste. Hydraulic binders (mortar, grout) are mainly used, but other materials (epoxy resins for example) may be preferred when the waste is liable to interact with a hydraulic binder type material and lead to degraded performance.

The packaging operations may be performed entirely on the production site or may require transit through a packaging facility shared by various producers. Operations are thus carried out by Andra on the CSA site (injection of containers, compacting of drums, packaging in the disposal vaults for certain large-sized waste) or by another industrial firm (for example: Socodei, Triade).

The main management facilities for LLW/ILW-SL type waste from the nuclear licensees are:

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[156] These radioactive waste package acceptance specifications define the main criteria with which a final radioactive waste package must comply in order to be accepted in the facility for disposal, more specifically its radiological, physical, mechanical and chemical properties. The licensee of a disposal facility must take steps to oversee compliance with these specifications by the waste accepted in its facility.

- for CEA, the effluent processing installations (STELLA, STEL MAR, STED PN) and the solid waste processing installations (BNI72, CDS in Marcoule, ICPE312 in Cadarache);
- for EDF, the waste processing and packaging buildings comprising:
    - the effluent treatment buildings (BTE) in the P'4 and N4 type NPPs,
    - the auxiliary packaging buildings (BAC) in the CP1, CP2, P4 type NPPs and on the Fessenheim site,
    - the general nuclear auxiliaries building (BANG) in the Bugey NPP.
- These installations are used for waste packaging (compacting, drumming, blockage in a hydraulic binder, etc.) and for storage of packages of LLW/ILW-SL waste pending shipment to the CSA or Centraco. They can also accept mobile units (called Mercure) operated by Socodei, which are periodically used to package used ion exchange resins;
- for Areva, the waste processing installations on the La Hague, Tricastin and Triade sites. These installations package and store the waste (before shipment to CSA or Centraco) for the needs of the site or for other customers. Packaging consists mainly of various operations involving compacting, placing in packages (drums, casks, etc.) and blockage or encapsulation using a hydraulic binder.

3.6.3 Melting/reutilisation

Certain metal waste are processed by melting which, depending on the physico-chemical characteristics of the waste, enables them to be decontaminated, at least in part, through segregation of the radionuclides in the various melting products and by-products.
The melting step may in particular be used to:

- reduce the volume of ultimate waste for disposal, as the ingots produced, which can be accepted in surface repositories, are denser than the unprocessed waste;
- characterise the waste and downgrade some of the LL category to the VLL category;
- recycle certain ferrous metals meeting precise metallurgical criteria.

The melting unit in the Centraco plant in Marcoule, operated by Socodei, processes VLL and LL metal waste: metal structures, valves, pumps, stainless steel, carbon steel, galvanised steel and non-ferrous metal tools used in maintenance and decommissioning of nuclear facilities, as well as secondary waste from incineration, such as packagings. The metal waste is sorted and prepared (sorting, shearing, cutting to size, etc.) then melted in an electric induction furnace with a capacity of four tons. The authorised processing capacity of the melting furnace is 3,500 t/year. Processing by melting of metal waste in the melting unit reduces the volume by a factor of 10 to 12.

From 1999 to 2011, about 21,700 tons of metal waste were processed in the melting unit, of which 600 tons were recycled in the form of integrated radiological shielding (PRI)[157] between 2002 and 2011 (an average of 55 t/year and nearly 140 tons in 2011). The melting furnace was shut down following an accident on 12th September 2011[158]. ASN authorised its restart in the resolution of 9th April 2015[159].

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[157] These PRI are inserted into the concrete containers for packaging LLW/ILW-SL type irradiating waste. They attenuate the ionising radiation and thus limit the dose rate on the surface of the resulting package.

[158] The incident report is available on the ASN website. http//www.asn.fr, heading « action de l'ASN », « contrôle », « actualités du contrôle », « avis d'incident des INB/2011 ».

[159] Decision by the ASN Chairman of 9th April 2015 authorising the Société pour le conditionnement des déchets et des effluents radioactifs (Socodei) to restart the melting furnace BNI n° 160, called CENTRACO and situated in Codolet (Gard *département*).

Experience feedback from manufacturing of PRI in Centraco demonstrates the feasibility of metal waste recycling for reuse in the nuclear sector. However, strict metallurgical constraints concerning the steel used to make up the PRI limits the quantities of reusable waste, because they entail significant preliminary sorting operations.

Similarly, recycling by melting of low level lead was set up in June 2003 in a facility on the Marcoule site (CEA), allowing decontamination of low level lead by melting. This solution was shut down in 2013 owing to the decommissioning of the facility containing the furnace. The average activity of the decontaminated lead leaving the furnace was no more than 0.5 Bq/g and it could then be shaped in three authorised conventional foundries (one operated by D'huart industrie and the other two by Robatel industrie). The physical separation of the streams was verified by means of audits and was based on traceability, on the organisation of the facilities concerned and on compliance with the specifications. Preparation of the low-level lead waste ahead of its introduction into the melting furnace however proved to be expensive (manual cutting, planing, separation of materials), which meant that economic profitability was borderline. The benefits of recycling by melting of lead was studied by Areva, CEA and EDF. This study identifies an inventory of about 12,000 t of LLW/ILW lead to be recycled and requiring consolidation. The benefit of any investment by the waste producers is more particularly tied to the possibilities for reuse of the decontaminated lead and the economic profitability of the solution, which need to be clarified.

R1 – Areva, CEA and EDF, together with Socodei when necessary, shall submit the preliminary design for a lead processing facility, before 31st December 2018.

3.6.4 Incineration

Incineration is the thermal process most frequently used in the nuclear industry around the world to process low and intermediate level radioactive waste. Its benefits are a significant reduction in the volume of the waste (by a factor of 10 to 20) prior to disposal and the ability to process a broad spectrum of waste: certain solid waste, organic liquid waste and aqueous liquid waste. The final waste is stable, chemically inert, non-dispersible and packaged in a format suitable for disposal.

In France, the radioactive waste incineration sector is based around the Centraco facility, operated by the Socodei company on the Marcoule site. The Centraco facility is today used by all the radioactive waste producers: Areva, CEA and EDF as well as Andra, which collects waste from small producers outside the nuclear power sector (mainly from hospitals and research laboratories).

Since its start-up in 1999, the Centraco incinerator has been a vital link in the management of the radioactive waste produced by the EDF NPPs in operation and now in the dismantling programme for the reactors shut down, which represents more than 90% by mass of the annual volumes delivered. Most of the very low level and low level technological waste, such as gloves, overshoes, work suits, plastic film, paper, rubber, etc., is solid incinerable waste and is processed in Centraco. Liquids such as oils, solvents and sludges from the facilities are also incinerated in Centraco. The installation allows the simultaneous incineration of liquid waste: oils, solvents and aqueous effluents.

Incineration can be used to process certain waste (oils, solvents) for which there was no management route and which, in certain cases, remained stored on-site. There are alternative solutions for the other waste (incinerable solids, aqueous effluents), for example packaging in metal drums or encapsulation in concrete shells for the Aube repository, **but, except for special cases, incineration generally remains the preferred option because of the significant reduction in volume it offers**. It also enables precise characterisation of the secondary waste created by the processing.

Since it was started up, the incineration furnace had processed nearly 24,500 t of incinerable solid waste (DSI) by the end of 2013, and 17,500 t of incinerable liquid waste (DLI). The following figure presents the quantities of waste processed since 1999.

Quantity of waste incinerated in the Centraco facility (source: Socodei)

Owing to the accident which occurred on 12th September 2011 on the Centraco melting furnace, the incinerator was shut down until mid-2012. In order to deal with the temporary closure of this solution, the BNI licensees adapted the management procedures for their incinerable waste (extension of storage capacity, use of packaging processes enabling the waste to be accepted by the CSA, etc.) and Andra doubled the stream of drums for compaction on the CSA. The waste management consequences were felt more strongly by the small producers even though Andra's collection service was not interrupted.

In order to reinforce the robustness of incinerable waste acceptance, new storage capacity is being envisaged at Centraco and Cires. Alternative solutions to processing are also being examined for EDF.

In order to increase the incineration capacity for incinerable solid waste and incinerable liquid waste, the operating range for the Centraco facility was the subject of successive expansion requests. The operating range of "Centraco 2", licensed in July 2014, more specifically allows the processing of tributylphosphate (TBP) solvents from the La Hague processing plant. The operating range of "Centraco 3" could, subject to licensing by ASN, allow the additional processing of 1,000 m^3 of leaching effluents (EDL) from EDF's NPPs and, if necessary, of new tritiated waste (orphan waste from Isotopchim, ITER, etc.).

3.6.5 Disposal

LLW/ILW-SL waste are emplaced in surface disposal repositories operated by Andra. Waste containment is built around a system of three successive barriers: the package, the repository structures and the soil on which the repository is built. After disposal of waste, the structures are closed and the facilities are subject to a monitoring and surveillance phase. The characteristics of the emplaced waste shall be such as to allow a monitoring and surveillance period of less than 300 years[160]. However, this monitoring and surveillance could be continued beyond this period and the memory of the site preserved for as long as possible.

The periodically updated facility safety reports, including during the monitoring and surveillance phase, must be able to check that the activity contained in the waste reaches a residual level such that human and environmental exposure is acceptable, even in the event of a significant loss of the containment properties of the facility.

There are two facilities of this type in France.

3.6.5.1. The Manche repository

The Manche waste disposal facility (CSM), which entered service in 1969, was the first radioactive waste repository operated in France. The CSM was operated for 25 years, from 1969 to 1994, during which the disposal conditions were continuously improved. In total, 527,000 m^3 of waste packages have been emplaced in it. Covering work was carried out from 1991 to 1997 and the facility entered the monitoring and surveillance phase in January 2003.

During the period the CSM was in operation, the groundwater circulating under the centre was contaminated by tritium in 1976. The waste which caused this contamination was removed, but the contamination of the groundwater is still significant, even if it is falling regularly. The evolution of this contamination is being closely monitored. The impact of the centre is however extremely slight (the impact on a hypothetical critical group was estimated in 2013 at 0.3 µSv/year).

The cover consists of a bituminous membrane to ensure leaktightness. The peripheral mounds were built within a very small perimeter, which led to instabilities. A programme of gradual consolidation of these mounds was defined by Andra and should take about fifty years. It comprises phases consisting of securing, consolidating and then reducing the steepness of the slopes down to the natural ground, interspersed with observation phases This programme requires an extension of the centre’s footprint, for which Andra has initiated the necessary land management process. An interim report on the covering works was sent to ASN in 2015.

The steps designed to preserve the memory of this repository are detailed in Appendix 1.

3.6.5.2. Waste disposal in the Aube waste disposal facility (CSA)

The practices used in the Aube waste disposal facility benefited from experience feedback from the Manche waste disposal facility.

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[160] The concept is more specifically in conformity with basic safety rule RFS I.2 of 1984 available on the website http://asn.fr

The packages are emplaced in concrete bunkers, sheltered from rain by mobile metal structures which can be moved as the facility is utilised. The packages are concreted or blocked by gravel in these structures, depending on whether the packages are perishable (metal drums and containers) or durable (concrete package). Once filled, the structure is closed by a slab, made tight to rainwater by spraying of a plastic material. The structures will then be protected by a cover with very low permeability, consisting of a layer of clay.

The CSA acceptance specifications are based on the facility's safety case and impact assessment. They aim to ensure safety for the long-term, but also during operation, for example by guaranteeing that the packages delivered are compatible with the processing and handling equipment in the facility. Andra also monitors the quality of the packages produced by means of audits on the producer sites. A second level of control is also carried out on the packages delivered to the waste disposal facility. Packages are sampled and assessed in approved laboratories on behalf of Andra. Andra decided to supplement its second-level control system by setting up an inspection facility in the Aube waste disposal facility, which it itself operates. Commissioning of this facility is planned for 2016, provided that the necessary licenses are obtained.

The specifications for acceptance in the CSA are restrictive with respect to waste containing tritium, on the one hand in order to comply with the liquid and gaseous discharge licenses and, on the other, to avoid medium-term contamination of the groundwater circulating below the centre, as tritium is a highly mobile radionuclide. Consequently, tritiated waste must undergo specific management as described in detail in Chapter 4.3.2. Similarly, the acceptance conditions for used sealed sources are also highly restrictive owing to their presumed attractiveness in the event of an inadvertent intrusion following a loss of all recorded trace (memory) of the site.

The CSA accepts disposal of "outsized" waste. Reactor vessel heads and other equipment items have therefore been emplaced without first being cut up for packaging in standard packages. However, unlike in Cires, the forecast inventory for this waste and the volume of deliveries to the CSA do not justify the construction of new dedicated structures. The conventional structures can be used, provided that certain operational measures are taken. This ability to accept large components is, as with Cires, an option for overall optimisation of waste management, from production to disposal, more particularly for decommissioning operations.

At the end of 2014, about 292,000 m^3 of waste packages were emplaced in the Aube repository, or about 29% of its regulation capacity. The volume of annual deliveries (12 to 13,000 m^3) is well below the design-basis volume (30,000 m^3).

With regard to the radiological capacity, the creation authorisation decree for the centre sets limits for 5 radionuclides as well as for the total alpha activity counted after 300 years. In addition, the prescriptions set out by ASN specify limits for 19 other radionuclides. These limits were determined on the basis of forecast inventories, by checking their compatibility with the facility's safety case, in both normal and altered evolution scenarios. The centre's consumption of its radiological capacity is at present less than its volume consumption, except for ^{36}Cl (the half-life of which is 300,000 years) because the inventory emplaced corresponds to nearly 90% of the authorised capacity. This situation is linked to the disposal of graphite sleeves stored on the Bugey site. The characterisation work carried out on the graphite waste detailed in Chapter 4.1 raises questions over the quantity of ^{36}Cl actually present in the waste of this type emplaced in the CSA.

The next CSA safety review is scheduled for 2016. On this occasion, the forecast inventory of waste to be accepted will be updated on the basis of the delivery forecasts submitted by the nuclear facility licensees. These data show that the capacity of the centre could become saturated by 2060, in other words well beyond the 30 years of centre operations as originally foreseen in the design. Decommissioning programmes should however lead to a gradual increase in volumes over the coming years.

I1 – Monitoring of CSA volume capacity.

I2 – Monitoring of CSAs radiological capacity, per radionuclide.

In addition to the issues linked to monitoring of the filling of the repository, the transport of LLW/ILW-SL waste also has an environmental impact. Efforts must therefore be made to optimise and thus limit transports.

R2 – Areva, CEA, EDF and Socodei shall submit a study before 31st December 2017 on transport procedures for LLW/ILW-SL waste, if necessary after processing, such as to reduce the environmental impacts.

4 The management routes to be implemented: current needs and future outlook

4.1 *Management of LLW-LL waste*

Low level, long-lived radioactive waste (LLW-LL) requires specific management, appropriate to its long lifetime, which rules out disposal in Andra's existing industrial facilities in the Aube *département*. This waste in particular comprises graphite waste from the operation and future decommissioning of EDF's gas-cooled reactors, radium-bearing waste, mainly from the processing of ores containing rare earths, some of the bitumen encapsulated waste drums from Marcoule and certain uranium conversion processing residues from the Comurhex plant in Malvési. Pending their disposal, following processing as and when applicable, the packages of LLW-LL waste are currently stored in facilities on the sites of the producers.

Andra has supplied an interim report on the creation of a disposal facility in the Soulaines area capable of accepting LLW-LL type waste. A 10 km² zone was selected in the north of this area for more detailed geological investigations.

The 2016-2018 PNGMDR asks that the geological investigations be continued on the site being studied, along with an assessment of the inventory of LLW-LL waste liable to be emplaced in it and the submission of a report in mid-2019 presenting the technical safety options for this disposal facility. Andra and the waste producers shall also continue with their studies of the radiological inventory, behaviour in the repository and the possibilities for processing of their LLW-LL waste.

An overall industrial system for management of all the LLW-LL radioactive waste shall also be submitted before the end of 2019.

4.1.1 Context and issues

Article 4 of Act 2006-739 of 28th June 2006 requires "the development of disposal solutions for graphite waste and radium-bearing waste". This waste is part of the low level, long-lived waste category (LLW-LL) for which the inventory is detailed in this part of the plan.

Graphite waste is produced mainly by the nuclear power sector (graphite sleeves, stacks from the first French fleet of gas-cooled reactors), while the radium-bearing waste comes mainly from industry (more specifically including waste with high levels of natural radioactivity), old radioactive objects (radium fountains, etc.) and certain used sealed sources (lightning arresters, smoke detectors, etc.). It requires specific management, appropriate to its long lifetime, which rules out disposal in repositories such as those operated by Andra in the Aube *département*. Their low level of radioactivity however means that they do not need to be sent for deep geological disposal.

Commissioning of at least one repository for LLW-LL type waste should be able to meet the needs of Solvay, EDF, CEA and Areva for management of their industrial sites, in particular for the necessary removal of waste from storage or decommissioning work, as well as for the needs of Andra for its public service duty to rehabilitate legacy sites which housed activities using radium or thorium, more than 50 years ago.

As a result of difficulties encountered in the initial siting process for a LLW-LL disposal repository[161], a further process was initiated in 2012 on the basis of the recommendations of an HCTISN report[162].

At the end of 2012, Andra submitted an interim report on the long-term management scenarios for LLW-LL waste which reached the conclusion that geological investigations were necessary to decide on the feasibility of near-surface disposal of radium-bearing waste. The possibility of including graphite waste, bituminous waste and other LLW-LL waste needed to be analysed on the basis of the results of the geological investigations and the work carried out to characterise these waste.

For the period 2013-2015, progress was made with regard to LLW-LL waste management concerning the following main aspects:

- The geological investigations carried out over an area of about 50 km^2 in the Soulaines region in the Aube *département*, close to the existing repositories, demonstrated that it was technically possible to continue to study near-surface disposal over a smaller area of 10 km^2;
- The producers drew up a list of "candidate" waste to be studied for near-surface disposal on the site investigated. They carried out additional characterisation work to improve the available data. This work helped bring about a significant reduction in the radiological inventory of ^{36}Cl and ^{129}I in the graphite waste and LLW-LL bituminous waste by comparison with the previous, conservative hypotheses. The available data on these waste will nonetheless need to be consolidated in the coming years.
- Andra, EDF and CEA have started R&D work to assess the behaviour of the waste in a disposal situation in cement and clay environments. This work contributed to the design choices, more particularly in terms of recommendations for the materials to be introduced into the repository, the definition of engineered components and architectural requirements for the disposal vaults. It must be continued.
- Andra examined disposal options based on industrially proven excavation techniques for construction of near-surface structures. These studies led to the first representations of disposal zone architectures and footprints.
- The preliminary phenomenological and safety assessments carried out for Andra's 2015 interim report show that the characteristics of the Soulaines site are favourable to receiving the LLW-LL waste examined in the interim report. However, this site will be unable to accept all LLW-LL waste, the scope of which is broader than that on which the 2015 interim report was based.

4.1.2 Characterisation of LLW-LL waste

4.1.2.1 Radium-bearing waste

Radium-bearing waste contains radionuclides of the three natural chains 4N (^{232}Th and its decay products), 4N+2 (^{238}U and its decay products) and 4N+3 (^{235}U and its decay products) with the 4N and 4N+2 chains being predominant. The average specific activity of the waste is about 20

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[161] A detailed history is given in the 2013-2015 edition of the PNGMDR.

[162] Report of 7th October 2011, available on the HCTISN website: http://www.hctisn.fr/.

becquerels per gram (Bq/g) of ^{238}U and of ^{232}Th and about 60 Bq/g of ^{226}Ra (between a few Bq/g and a few hundred Bq/g depending on the waste).

The inventory of radium-bearing waste currently comprises:

- legacy waste resulting from the extraction of rare earths from monazite ore: radium-bearing residues (RRA) and general solid residues (RSB) from Solvay;
- the raw thorium hydroxide processing residues, which will be produced if Solvay subsequently opts for recovery of the thorium, uranium and rare earths;
- the waste from the manufacture of zirconium sponges, zirconium and hafnium salts, from zircon ore and zirconium oxide melted since 2012 (Cézus plant in Jarrie belonging to the Areva group);
- some of the waste from the Itteville landfill (former settling pond and disposal area, annexe to the Le Bouchet plant) consisting of tailings and hydroxides (CEA);
- the waste from the post-operational clean-out operations on sites polluted with radium, uranium and thorium, managed by Andra as part of its public service duties.

4.1.2.2 Graphite waste.

The graphite waste produced and held by EDF and CEA represent about **21,700 tons before packaging**. They can be differentiated according to their origin in the reactors: graphite stacks and biological shielding on the one hand and nuclear fuel cartridge sleeves on the other.

The waste produced and held by Areva, which stores them in silos on the La Hague site, represent just under 1,100 tons and come from processing of gas-cooled reactor fuels between 1966 and 1990. They are characterised by the presence of mainly graphite (sleeves) mixed with magnesium (cladding, plugs, centring devices), stainless steel (retaining wire) and uranium residues.

EDF, CEA and Andra have set up study and research programmes to specify the radiological content of the graphite waste and assess their behaviour in the repository. Particular attention was given to the inventory of ^{36}Cl and ^{14}C, which make the main contribution to the long-term radiological impact.

The characterisation work carried out until the beginning of 2015 by CEA and EDF[163] on their graphite waste led to a significant reduction in the radiological inventory of ^{36}Cl, by comparison with the previous conservative hypotheses utilised in the disposal studies. The estimated radiological inventory of ^{36}Cl (consisting mainly of the above-mentioned CEA and EDF waste) now used is thus about 2 TBq, which is still a conservative value.

4.1.2.3 Bituminous waste

CEA is continuing its radiochemical characterisation programme for legacy packages of LLW-LL type bitumen encapsulated sludges, which it started in the early 2000s. These drums of bituminised sludges were produced as of 1966 in the STEL, the liquid effluent treatment station, in Marcoule. The LLW-LL inventory concerned is 32,901 drums of bituminised sludges, corresponding to a

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[163] State of knowledge of the radiological content of CEA and EDF graphite waste intended for LLW-LL near-surface disposal. Particular focus on chlorine 36. This report submitted pursuant to the 2013-2015 PNGMDR is available on the websites of ASN and the Ministry responsible for energy:

- http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015 ;
- http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

total volume of bituminised sludge packages repackaged in stainless steel over-packs equal to 12,503 m^3.

Improved knowledge of the radiological inventories of legacy packages of bituminised sludges is obtained from the operations to retrieve packages of legacy waste. These retrieval operations consist in placing the packages in stainless steel over-packs, for further storage in nuclear facilities called EIP – multi-purpose interim storage facilities. The study of the radiochemical and physico-chemical characteristics is based on the analysis of samples taken from a percentage of the drums of bituminised sludges (up to about 5% of the inventory) from different manufacturing periods, combined with a gamma spectrometry nuclear measurement of each drum retrieved. The nuclear measurements and radiochemical analyses are also correlated with the radiological activity levels deduced from the information concerning the effluent received in the STEL for processing/packaging.

A summary of the work to characterise the physico-chemical variability of these packages of bituminised sludges was submitted by CEA in compliance with the 2013-2015 PNGMDR[164]. It defines five physico-chemical families according to a variability range for the levels of their chemical compounds. Minimum and maximum composition bounds (% by mass) are defined for about 15 to 20 chemical components characterising the encapsulated bituminised sludges.

4.1.2.4 Waste from the AREVA NC plant in Malvési requiring a LLW-LL management route

These waste are described in detail in Chapter 4.3 (section 4.3.5).

4.1.3 Packaging and processing options

4.1.3.1 Packaging of graphite waste

EDF has developed a new reinforced concrete container for packaging its graphite waste, after consultation with Andra. The waste would be placed in a metal basket and then in a concrete container. The blocking grout would then fill the interior before being closed by a plug, also made of concrete. CEA intends to use the same packaging for its graphite waste. Packaging of the EDF and CEA graphite waste will lead to a volume of about 80,000 m^3 for disposal.

For the decommissioning of its gas-cooled reactors, EDF is examining two options for injection of the graphite packages:

- a facility on each site, in which case the mass of the package must comply with the transport mass criterion. This would mean a larger number of packages produced;
- a centralised facility which would make it possible to share the graphite package injection means on a single site, close to the final disposal location, which would enable the decommissioning operations to be separated from the graphite waste packaging operations.

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[164] State of progress in characterisation of ILW-LL waste produced before 2015 – Waste packaging study programmes (CEA report submitted pursuant to the 2013-2015 PNGMDR also available on the websites of ASN and the Ministry responsible for energy, at the above-mentioned addresses).

The initial scenario with retrieval of the graphite/magnesium cladding waste from the silos at La Hague aims to recover the waste with a gripper and place it in intermediate packagings for blockage with a cement grout. These intermediate packagings of blocked waste would then be placed in a package. However, the packaging scenario has not yet been finally determined.

4.1.3.2 Graphite waste processing

- *Context*

Management solutions based on processing of graphite waste concerned two of the three graphite waste management solutions that are alternatives to intact cover disposal (SCI), which were evaluated by Andra in its report submitted to the Government[165] at the end of 2012:

- waste sorting for disposal of the stacks in reworked cover disposal (SCR) and of the sleeves in the planned Cigeo repository;
- extraction of radionuclides (^{36}Cl, ^{14}C, ^{3}H, etc.) with disposal of the partially decontaminated graphite in an SCR and the concentrated residues in the planned Cigeo repository;
- total destruction (by gasification) of the graphite after decontamination, with disposal of the processing residues in the planned Cigeo repository.

- *Processing principle*

The processing studied consists in raising the previously crushed graphite to high temperature (about 1000°C) in a furnace swept with a gas mixture with the aim of extracting volatile or partially volatile radionuclides (^{14}C, ^{36}Cl, ^{3}H…). The radionuclides entrained by the gas flow are trapped and stabilised for packaging and subsequent disposal in an appropriate facility.

During processing, the operating conditions are checked to limit the destruction of the graphite matrix and promote selected decontamination of the ^{14}C as opposed to the stable ^{12}C, which is easily the principal component of the nuclear graphites[166]. Processing of the gas resulting from the decontamination operation generates secondary waste, the quantity of which is partially proportional to the quantity of gasified stable carbon. To avoid generating excessive amounts of secondary waste, it is therefore essential to maximise the selectivity of ^{14}C extraction.

In line with the alternative management scenarios identified in 2012, the aim is to be able to resort to total gasification of the graphite following this initial thermochemical processing step. This solution could only be envisaged if the atmospheric discharges of gasified graphite were to be acceptable, which implies a high level of decontamination performance.

- *Work initiated – Results obtained*

R&D work has been initiated in three main areas:

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[165] This report on the "Study of long-term management scenarios for low specific activity, long-lived waste" of 21st December 2012 is available on the Andra website: http://www.andra.fr.

[166] The ^{14}C / ^{12}C isotopic ratio in the graphite waste is about 10^{-7}.

- laboratory research on irradiated graphite samples, with optimum operating conditions maximising the performance of the long-lived activation product decontamination step and the understanding of the mechanisms involved;
- demonstration of the industrial feasibility of processing, with EDF carrying out "preliminary design" studies of a semi-industrial processing prototype;
- the acceptability in the repository of processing secondary waste, on the basis of exchanges between EDF and Andra.

As it stands in 2015, the work carried out demonstrates the feasibility in the laboratory of partial decontamination of the graphites, especially ^{14}C.

- *Outlook*

Together with CEA and Andra, EDF is not at present abandoning the possibility of defining and then implementing a solution based on thermochemical decontamination of irradiated graphites[167] prior to their disposal. A research and monitoring programme is thus continuing, in particular through a study of the influence of heat treatment on speciation and on the release of radionuclides. Results enabling a conclusion to be reached on the benefits of implementing such a solution are expected for the 2017 time-frame.

4.1.4 Storage

4.1.4.1 Radium-bearing waste

The radium-bearing residues, packaged in about 26,000 drums of 220 litres, are stored in ICPEs 420 and 465 on the CEA site in Cadarache, on behalf of their owner, Solvay. The general solid residues are stored on the Solvay site in la Rochelle. This waste is placed in bulk on a leaktight area under a tarpaulin. It represents a mass of 8,400 t.

The Areva waste is stored in a dedicated building on the Jarrie site. As at the end of 2013, the mass of carbochlorination residues was evaluated at 2,020 t, that of sublimation residues at 715 t, leading to 2,075 t of waste before stabilisation. The quantity of waste to be produced by 2032 is estimated at about 3,700 tons after stabilisation. Since 2005, non-stabilised waste has been packaged in reinforced steel drums of 220 L. The storage building in Jarrie has a surface area of 6,000 m^2 and a regulation capacity of 4,500 t. On the basis of current production rates, this means that it will be able to provide storage capacity until 2032.

Waste from CEA's Itteville disposal site is stored under a clay covering on a site adjoining that of the former Bouchet plant. The total mass of waste stored is 40,000 t, of which 28,000 t appear to be VLLW and 12,000 t LLW-LL.

Other types of LLW-LL waste from sectors outside the nuclear power industry are stored by Andra in its new LLW-LL type waste storage building, authorised by the order of 9th February 2012 and

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The Areva graphite and magnesium waste from processing of GCR fuels and stored in silos 115 and 130 on the La Hague site, are not candidates for possible reprocessing, insofar as the upstream sorting operations cannot guarantee the absence of substances incompatible with the treatment process.

situated on the site of the Cires disposal centre. This facility has a storage capacity of 6,000 m^3. As at the end of 2014, the volume stored was 690 m^3. The total volume of waste to be stored is uncertain, owing to the number of polluted sites to be rehabilitated and the level of remediation required.

The future requirement in terms of storage capacity for radium-bearing waste is linked to the date of availability of a disposal solution for this waste.

4.1.4.2 Graphite waste

Graphite waste represents a mass of about 23,000 t. Most of it will be produced during dismantling of the old gas-cooled reactors.

The graphite sleeves from the Saint-Laurent A reactor (EDF) are stored on-site in semi-buried silos. They represent a mass of about 2,000 tons.

The graphite sleeves from the Chinon A2 and A3 reactors are stored on the CEA Marcoule site in the MAR 400 facility pits and in the cladding removal facility. They represent a mass of about 750 t. The retrieval and packaging of this waste is scheduled as part of the Marcoule post-operational clean-up and decommissioning programme to be completed by 2035.

The Areva graphite and magnesium waste comes from processing of gas-cooled reactor fuels. It represents a mass of about 1,100 tons and is stored in silos 115 and 130 at La Hague. The programme to retrieve waste stored in these silos makes provision for packaging in special packages for storage in a dedicated building on the La Hague site, pending the opening of a disposal route.

The future storage capacity requirement for the graphite waste already produced and that to be produced by decommissioning operations, is linked to:

- the date of provision by Andra of a disposal solution for these waste, as well as its annual acceptance capacity;
- the EDF and CEA gas-cooled reactors decommissioning schedule;
- the safety constraints on existing facilities.

The graphite waste to be generated by the decommissioning of reactors G1, G2, G3 in Marcoule represents about 3,800 t. CEA's current schedule anticipates their retrieval as of 2030 (pending the availability of a LLW-LL disposal centre, for removal of the waste packages as and when produced).

The quantities of graphite waste to be produced by the EDF gas-cooled reactor decommissioning operations represent 15,000 t of stacks currently stored in the reactor tanks, to which must be added the 2,000 t of sleeves stored in the Saint Laurent A silos.

EDF has at present chosen to only engage work to dismantle the core of its shut-down gas-cooled reactors once Andra has commissioned a disposal facility for LLW-LL type waste, so that the graphite waste thus generated can be sent to it as and when it is produced. Thus, removal of the first graphites during decommissioning of the tank in BUG1, the first-off gas-cooled reactor, is scheduled by EDF as of 2025.

4.1.4.3 Drums of bitumen encapsulated LLW-LL type waste

The drums of bitumen encapsulated waste (LLW-LL or ILW-LL categories) are currently stored in bunkers in the STEL in Marcoule, built between 1966 and 1994, while others are stored in multipurpose storage (EIP) type vaults All the bunkers are scheduled to be gradually emptied. Some of the drums have in fact already been extracted and repackaged in stainless steel overpacks for storage in the EIP (multipurpose interim storage facility commissioned in 2000), and CEA has provided the defence nuclear safety regulator (ASND) with a commitment to retrieve 32,500 drums before 2027. All the 60,000 drums should be retrieved by the end of 2035, depending on the conditions of availability and acceptance by the final disposal solutions. The storage strategy on the Marcoule site is also based on the possibility of removing the drums of LLW-LL bitumen to near-surface disposal as of 2025.

4.1.4.4 Waste from the settling ponds in the Areva NC plant in Malvési

The case of legacy waste stored on the Areva NC site in Malvési is dealt with in Chapter 4.3.

The waste "to be produced" by the ICPE during the course of the installations modernisation project, that is as of 1st January 2019, will be stored in the location of the current settling ponds B5 and B6. In its study, Areva NC plans in the short term to construct storage vaults or racks on the site of these two settling ponds. For the long-term management of these waste, Areva presented a joint long-term management solution including that of the waste already produced: disposal on-site, using several disposal concepts. In its resolution 2012-AV-0166 of 4th October 2012, ASN stated that a distinction needs to be made between management of waste "already produced" and that "to be produced", and that this latter should be managed in appropriate routes meeting the requirements in force for the management of radioactive waste.

4.1.4.5 Technological waste produced by the La Hague plants

According to Areva, some of the technological waste packaged in cylindrical concrete-fibre containers, called CBF-C2 packages, are "candidates" for near-surface disposal. Depending on their activity level, these packages of technological waste had hitherto been sent for surface disposal or headed towards Cigeo. Insofar as the composition and activity levels of these packages are homogeneously spread, sorting could enable some to be sent to a LLW-LL category, which were therefore taken into account in the inventory studied in the interim report.

4.1.5 Recommendations and outlook

The preliminary phenomenological and safety assessments carried out for the 2015 interim report show that the characteristics of the Soulaines site are favourable to receiving the LLW-LL waste families considered in the interim report.

However, in its resolution of 29th March 2016[168] ASN considers that it is *"unlikely that the inventory envisaged in the interim report could be disposed of on the site investigated by Andra"*. In addition, the studies

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[168] ASN opinion 2016-AV-0264 of 29th March 2016 concerning the studies on the management of low level, long-lived waste is available on the website: http://www.asn.fr, heading « les actions de l'ASN », « la réglementation », « bulletin officiel de l'ASN », « avis de l'ASN ».

carried out by Areva show that some of the waste from the Malvési site to be produced as of 1st January 2019 are compatible with near-surface management, that is the LLW-LL route. These waste are not taken into account in the inventory studied in Andra's interim report.

Because the site investigated by Andra cannot accept all of these waste, a roadmap must be defined for a management strategy for all the LLW-LL waste, including those produced as of 1st January 2019 on the Malvési site and compatible with a LLW-LL management route. This management strategy must be tailored to the heterogeneity and harmfulness of these waste, proportionate to the safety, technical and economic implications and envisaged in accordance with a realistic calendar. It shall be based on an industrial system combining:

- the site investigated in the Soulaines area,
- another site to be looked for, concerning the waste which it will not be possible to send to the Soulaines site and with a view to overall optimisation of impacts,
- continued studies on waste characterisation (the radiological inventory in particular),
- studies on the sorting or processing processes upstream of disposal, as related to the condition of acceptability on the sites,
- as an interim measure, the inclusion of certain waste in the Cigeo reserves or reference inventory, following on from the recommendations of the previous PNGMDR.

This overall strategy must be drafted sequentially by all the stakeholders in the sector. For this purpose:

- Andra will be continuing its investigations on the Soulaines site and, before mid-2019, will be presenting the preliminary technical and safety options for a near-surface disposal facility, specifying the inventory of the waste it envisages emplacing there. This inventory could be a sub-part of the inventory considered in the 2015 interim report;
- Andra and the waste producers will produce an overall industrial system before the end of 2019.

In parallel with these works, ASN intends to work on updating its safety guide concerning near-surface disposal of LLW-LL waste.

These objectives are covered by the following recommendations:

1) Soulaines site

R1 – Andra will be continuing its geological investigations on the Soulaines site and before 30th June 2019 will submit the (preliminary) technical and safety options for a near-surface disposal facility. Before 30th June 2018, Andra will also be submitting an interim report which, together with the design studies, will define the safety requirements applicable to the repository.

In the report expected before 30th June 2019, Andra will:

- clarify the inventory liable to be disposed of in this facility;
- draw up the list of essential requirements concerning the packaging of the waste intended for this repository, to guarantee protection of the interests mentioned in Article L. 593-1 of the Environment Code, during operation of the facility and during the monitoring and surveillance phase;

- present a safety assessment of the degree of protection the repository is capable of offering against the risks of intrusion and the dissemination of radioactive and chemical substances, more particularly into the underlying aquifer, and the robustness of the safety case. These elements will in particular be defined on the basis of the Order of 7th February 2012 and the ASN recommendations made in the opinion of 29th March 2016;
- provide a forecast estimate of the cost of disposal of these waste at the end of the facility's service life.

R2 – Andra shall transmit a safety options file (corresponding to a preliminary design stage) before 31st December 2021. By 31st March 2017, Andra will propose a prudent target commissioning date for the repository.

R3 – Before 31st December 2017, EDF and CEA shall submit an interim report on the studies on the processing-decontamination possibilities for graphite waste. According to the results of this interim report and provided that processing of graphite waste is necessary for it to be accepted in the repository, EDF and CEA shall submit a file by 31st December 2019 presenting the technical and safety options (preliminary design stage) for a graphite waste processing facility.

R4 – CEA and EDF must continue and finalise their studies in order to make sure that the radiological inventory of the graphite waste is reliable:
- **In order to consolidate the inventory reverse evaluation method, EDF and CEA must use additional measurement campaigns to confirm the conservative nature of the total ^{36}Cl inventory currently presented. EDF must complete its measurements and submit a study presenting its results and conclusions before 30th June 2019. EDF shall in particular specify the ^{36}Cl radiological content of its graphite waste, a large part of which is accounted for by the Saint-Laurent A1 and A2 sleeves. CEA must complete its measurements before 31st December 2021 and submit a study presenting its results and interim conclusions before 30th June 2019;**
- **CEA, EDF and Andra must make progress in describing the behaviour of the ^{14}C contained in the graphite waste placed in disposal conditions, in particular its speciation and the nature of the corresponding organic molecules and the kinetics of their release.**

The initial results of these studies should be available to help produce the Andra preliminary file planned for 2019.

2) Overall industrial system

R5 – Together with the waste producers, Andra will submit an overall industrial system for management of all the low level, long-lived radioactive waste, before 31st December 2019, taking account of the following requests:
- **an inventory more specifically including the graphite waste, LLW-LL bitumens, radium-bearing waste and the fraction of the waste produced as of 1st January 2019 in the AREVA NC plant in Malvési which is compatible with a LLW-LL management route;**

- **continued investigations on the Soulaines site for siting of a disposal facility. The inventory of waste liable to be disposed of on this site shall be clarified and substantiated;**
- **the search for a second near-surface disposal site, as a priority on or near to existing BNIs and SBNIs;**
- **the inclusion of certain LLW-LLW waste in the Cigeo reference inventory and reserves.**

3) Search for a new disposal site

R6 – Before 30th June 2018, Andra will present the methodology for the search for a second LLW-LL disposal facility in accordance with the HCTISN recommendations of 7th October 2011, giving priority to a search on or near to existing BNI and SBNI sites, along with the corresponding inventory.

4) Precautionary measures

R7 – As a precautionay measure and consistently with the ongoing design studies for the Cigeo project:

- **the following waste remain included in the reserves of the Cigeo inventory (see recommendation R27 in the HLW/ILW-LL chapter): graphite waste (sleeves), LLW-LL bitumen encapsulated waste (not processed) and gas-cooled reactor waste from La Hague;**
- **the following waste remain included in the Cigeo reference inventory: CBF-C'2 waste.**

R8 – On the basis of the industrial management system for LLW-LL waste, the producers and owners of LLW-LL waste will define and send the following to the Ministers responsible for energy and defence and to ASN, before 31st December 2017:

- **the existing storage capacity, specifying availability;**
- **the saturation or end of operation forecasts for this capacity and the need for new capacity over the coming 30 years, taking account of the BNI decommissioning operations carried out in accordance with Article L. 593-25 of the Environment Code;**
- **the time needed to commission new storage capacity.**

The calendar for provision of a LLW-LL waste management route, delayed with respect to the initial forecasts, requires the retrieval of certain legacy waste from the storage facilities. This is more particularly the case of the Saint-Laurent des Eaux silos.

R9 – Before 31st December 2019, EDF will send the Minister responsible for nuclear safety and ASN the technical and safety options (preliminary design level) for a graphite waste storage facility concerning the waste stored in the Saint-Laurent-des-Eaux silos and, as necessary, the waste produced by decommissioning of the reactor which will be the first gas-cooled reactor to be decommissioned, if the production calendar for these waste is not compatible with the calendar for commissioning of and receipt of waste in the first LLW-LL repository.

4.2 Management of HLW and ILW-LL waste

The management of HLW/ILW-LL waste is studied according to the three complementary focal points identified in the 28th June 2006 Act on the sustainable management of radioactive materials and waste, now codified in the Environment Code: reversible disposal in a deep geological layer, storage and the partitioning and transmutation of long-lived radionuclides. Research is also being carried out into the processing and packaging of these waste.

The Environment Code identifies deep geological disposal as the solution for the long-term management of ultimate radioactive waste which cannot be disposed of on or near the surface, for nuclear safety or radiation protection reasons. The underground installations of the planned disposal facility called Cigeo (French acronym for geological disposal industrial centre) would be situated within a layer of clay at a depth of about 500 m. The research carried out by Andra in the Meuse/Haute Marne underground laboratory enabled important results to be obtained on the Bure site with regard to the feasibility and safety of a repository. **Following the 2013 public debate on the "planned reversible deep disposal facility for radioactive waste in Meuse/Haute-Marne", Andra made a number of adjustments to the project, more specifically including the submission of a safety options file in 2016 and the integration of a pilot industrial phase prior to start-up of the installation. The definition of the notion of reversibility was also clarified by Parliament in the 25th July 2016 Act. Receipt of the first packages of radioactive waste is now scheduled for approximately 2030.**

Storage allows the safe management of HLW/ILW-LL waste pending the opening of a long-term management facility. The waste packages are stored in facilities on the sites of the producers. **The analysis of the storage needs for HLW and ILW-LL waste packages shall be completed by Areva, CEA and EDF, together with Andra, adopting significant time margins and taking account of the scheduling of shipments to the planned Cigeo repository and of the principle of reversibility.**

The studies being carried out into partitioning-transmutation, coordinated by CEA, aim to assess the industrial feasibility of the solutions for separating certain minor actinides from the ultimate waste. Even if the studies show that partitioning transmutation can be considered a potential means of improving waste management, there are nonetheless a certain number of drawbacks with regard to both nuclear safety and radiation protection (difficulties with cycle operations, etc.). Furthermore, they do not preclude the need for geological disposal.

4.2.1 Context and issues

The three areas for study and research

Planning Act 2006-739 of 28th June 2006 concerning the sustainable management of radioactive materials and waste requires that the management of high level (HLW) or intermediate level, long-lived (ILW-LL) waste be the subject of three complementary avenues of research:

- the partitioning and transmutation of long-lived radionuclides, linked to the research being conducted on the new generations of nuclear reactors, as well as accelerator driven systems dedicated to the transmutation of waste, so that by 2012, an assessment can be made of the

industrial prospects for these solutions, with service entry of a prototype facility before 31st December 2020;
- reversible deep geological disposal, with the aim of selecting a site and designing a repository for commissioning in 2025, subject to the corresponding authorisations being granted;
- storage[169], with the aim of creating new storage facilities or modifying the existing ones in order to address the needs identified by the PNGMDR.

The first area of research, coordinated by CEA, concerns waste which would be generated by future nuclear power reactors as well as certain types of spent fuels not processed in the existing facilities. The other two areas of research, coordinated by Andra, concern ILW-LL and HLW waste already produced (which, as at end 2013, represented 44,000 m^3 of ILW-LL waste and 3,200 m^3 of HLW waste, or about 60% ILW-LL waste and 30% HLW waste according to the data of the 2015 edition of the National Inventory) or still to be produced by the current facilities and those under construction which received their creation authorisation decree by 31st December 2012, considering an average operating life of 50 years.

The Environment Code identifies deep geological disposal as the benchmark solution for the long-term management of ultimate radioactive waste which cannot be disposed of on or near the surface, for nuclear safety or radiation protection reasons, with storage being used to offer the necessary flexibility and allow gradual and controlled implementation of this solution. Article L. 542-1-2 of the Environment Code states that: *"after storage, ultimate radioactive waste which, for nuclear safety or radiation protection reasons, cannot be disposed of on or near the surface, shall require deep geological disposal"*. European directive 2011/70/Euratom of 19th July 2011 also recalls that *"the storage of radioactive waste, including for the long-term, is only a temporary solution which cannot be considered an alternative to disposal"* and that *"it is commonly accepted from the technical standpoint that deep geological disposal is currently the safest and most durable solution as the final step in the management of high level waste and spent fuel considered to be waste"*.

According to the law, storage does not aim to provide an alternative to deep geological disposal, but is examined as a complement to this reversible disposal. It should in any case be able to guarantee the safe management of HLW and ILW-LL waste pending the commissioning of a deep geological disposal facility and, should it prove impossible to demonstrate the safety of such a facility or if the decision to create such a facility is not taken, storage should then make it possible to wait for the implementation of a new final solution.

In France, this choice of deep geological disposal as the benchmark solution was made by Parliament following 15 years of research carried out pursuant to the 30th December 1991 Act on radioactive waste management research. This research led to the following conclusions:
- the technical feasibility of partitioning and transmutation has not yet been proven and even if this solution were to be implemented, not all the HLW and ILW-LL radioactive waste would be eliminated;
- long-duration storage could not constitute a final solution for the management of high level, long-lived radioactive waste because it implies maintained oversight on the part of society and the retrieval of waste by future generations, which would be hard to guarantee over a time-frame of several centuries;

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[169] Storage is defined in Article L. 542-1-1 of the Environment Code as "the operation consisting in temporarily placing [the radioactive waste] in a specially designed surface or near-surface facility, with the intention of subsequently retrieving it".

- the key aspects of the feasibility of a geological repository indicated that demonstration of the safety of a repository in clay, examined by means of the Meuse/Haute-Marne laboratory, was highly probable.

Disposal in a deep geological formation was thus identified as an inescapable final management solution.

HLW and ILW-LL waste

HLW waste chiefly consists of fission products and minor actinides separated from uranium and plutonium during processing of spent fuels. The reprocessed plutonium and uranium are materials that can be reused in pressurised water reactors (second and third generation) and then, in the longer term, in fourth generation fast neutron reactors which could come on-stream no earlier than the middle of the century (see § 2.3).

In the meantime, the spent fuels were systematically included by Andra in the feasibility studies for geological disposal concepts. In 2005, Andra thus acquired key data on the technical feasibility of the direct disposal of spent fuels in Cigeo. The studies carried out by Andra since then have led to interim reports. The first in 2012 and a second expected for 2016, with the purpose of confirming that the changes made to the project since 2005 do nothing to compromise these findings.

Most ILW-LL waste comes from the nuclear fuel cycle (metal structures of spent fuels, operating waste and solidified effluents from the spent fuel processing plants and the MOX fuel fabrication plants). Reactor operating and dismantling waste and the waste produced by CEA's activities also fall into this category.

Progress on the Cigeo project

Andra is carrying out studies into reversible disposal in a deep geological layer, more specifically in the Meuse/Haute-Marne underground laboratory and in the zone of interest for detailed reconnaissance (ZIRA) the perimeter of which was validated by the Government in 2010. In 2011, Andra initiated the industrial design phase for the Cigeo project, which should be continued with a view to submission of the creation authorisation application file, which will be examined by ASN. Receipt of the first radioactive waste packages is scheduled for approximately 2030.

During the period 2013-2015 major progress and modifications were made on the Cigeo project.

In 2013, the national public debates commission (CNDP) organised 6 months of public debate on "*the planned reversible deep geological repository for radioactive waste in Meuse/Haute-Marne*". In addition to this and given the difficulties encountered in holding public meetings, the CNDP asked that a conference of citizens be organised. 17 individuals drawn by lots thus drafted an opinion after 3 training weekends. The conclusions of the public debate and the opinion of the conference of citizens[170] led Andra[171] to make a number of adjustments to the project:

- integration of an industrial pilot phase prior to start-up of the facility;
- implementation of a regularly revised operations master plan;

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[170] These documents are available on the CNDP website http://cpdp.debatpublic.fr/cpdp-cigeo/informer/documents-cpdp/compte-rendu-bilan-debat.html

[171] Deliberation of the Board of Directors of the French National Agency for Radioactive Waste Management of 5th May 2014 relative to the follow-up to the public debate on the Cigeo project.

- postponement of the Cigeo creation authorisation application;
- greater involvement in the project by civil society.

Following the public debate, Andra continued with the design of the project by running an industrial preliminary designs optimisation phase incorporating the modifications made by the public debate and then managing the execution of the preliminary designs. The last industrial design phase preceding submission of the creation authorisation application - transition to the detailed design phase - started at the end of 2015 and should continue until 2017.

In early 2016, Andra will send the project's safety options to the State and ASN. These documents will present the options selected by Andra to ensure the safety of the facility during its operation and after its closure, as well as the possibilities for retrieving the emplaced radioactive waste packages. ASN notified Andra of its requirements regarding the contents of this file[172]. ASN also decided to submit this safety options file for an international peer review organised by IAEA.

The definition of the notion of reversibility was clarified by Parliament (Act of 25th July 2016), in accordance with the provisions of Article L. 542-10-1 of the Environment Code.

R1 – To ensure the satisfactory sequencing of all the steps in the management of HLW and ILW-LL waste, in preparation for the next edition of the PNGMDR, Andra shall, if necessary, update the calendar for the Cigeo project by 30th June 2017, specifying the foreseeable dates for the submission of the creation authorisation application, the beginning of the pilot industrial phase and the commissioning of the repository. This schedule shall be in conformity with the level of requirements of the safety case at these various steps.

4.2.2 The processing and packaging of waste

The purpose of processing and packaging radioactive waste is to "reduce the quantity and harmfulness of the radioactive waste" as required by the Environment Code. Using procedures appropriate to the nature and characteristics of the radioactive waste, these operations should also allow the production of radioactive waste packages guaranteeing the confinement of the radioactive and hazardous substances they contain as well as their physico-chemical stability, while limiting the heterogeneity of their distribution within the radioactive waste package. When necessary, they help improve the resistance to chemical and biological agents and facilitate the removal of the heat produced by radioactive decay. In the particular case of deep geological disposal, the constraints involved in package recoverability must also be taken into account.

With regard to the packages already produced, Andra shall take account of their characteristics in its design studies and ensure that they can be accepted. As necessary, if the adoption of design measures enabling them to be accepted in the Cigeo deep geological repository is not possible in acceptable technico-economic conditions[173] or for reasons of safety, repackaging operations will need to be carried out by those in possession of them.

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[172] ASN letter to Andra on 19th December 2014 (reference: CODEP-DRC-2014-039834), available on the ASN website: http://www.asn.fr/Informer/Actualites/L-ASN-fait-part-a-l-ANDRA-de-ses-attentes-sur-le-contenu-du-dossier-d-options-de-surete.

[173] These conditions must be examined in the light of the overall cost of managing the waste concerned.

With regard to the packages yet to be produced, the processing and packaging methods must be examined with a view to technical/economic optimisation of the entire management chain for the waste produced, in the best conditions of safety for the sites of the licensees producing it and for the safety and reversibility of deep geological disposal. In any case, they shall have no characteristic ruling out disposal and shall be compatible with the requirements of the Cigeo deep geological disposal project as at the date they are produced. In accordance with Article 6.7 of the Order of 7th February 2012 setting the general rules for BNIs, their packaging must first be approved by ASN, pending the definition of the specifications for package acceptance in Cigeo.

R2 – Andra shall define a preliminary version of the acceptance specifications[174] for the deep geological repository it is designing, as early as possible. When drafting these specifications, it shall make efforts to take account of the radioactive waste packages already produced and of whose characteristics it has been informed, more particularly through the waste package data files[175].

R3 – Within a time not to exceed 24 months following the date of transmission of the draft preliminary acceptance specifications for Cigeo, the producers of HLW and ILW-LL waste shall produce an acceptability analysis for the packages of radioactive waste produced as at this date, with respect to the preliminary version of the preliminary acceptance specifications for Cigeo transmitted by Andra.
1) With regard to the families of radioactive waste packages currently being produced or those for which production is planned within the next 10 years, this analysis should be able to identify any incompatibilities between the expected characteristics of the packages to be produced and these specifications. If such cases are identified, the producers of HLW and ILW-ILL waste concerned shall update their packaging strategy.
2) With regard to the families of radioactive waste packages for which production is completed as at the date of transmission of the draft preliminary acceptance specifications for Cigeo, this analysis shall be able to identify (i) any incompatibilities between the characteristics of the packages produced and these specifications and (ii) the additional data to be acquired to improve the understanding of the packages in the light of the requirements contained in these specifications.
If such cases are identified:
(i) A technical dialogue is initiated between Andra and the corresponding waste producers, to define the appropriate methods for dealing with these deviations.
(ii) in the light of this analysis, the producers of HLW and ILW-LL waste present the study programme to be implemented.

As necessary, the time-lines for the delivery of waste packages to the planned deep geological repository are updated.

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[174] This document is drafted as a preliminary to the production of the repository acceptance specifications. These acceptance specifications will eventually define the main criteria with which a final radioactive waste package must comply in order to be accepted in the facility for disposal, more specifically its radiological, physical, mechanical and chemical properties.

[175] The waste package data files are drawn up for the various families of HLW and ILW-LL packages by their producers, in accordance with the best practices mentioned in appendix 1 to the safety guide for final deep geological disposal of radioactive waste.

4.2.2.1. Packaging of HLW waste

Vitrification, using the “hot crucible” technology, in the Marcoule and then La Hague processing plants, is today the reference industrial process in France for packaging of fission product solutions from spent fuel processing. With more than twenty years of experience and the combined production of more than 16,000 vitrified packages, this technology can now be considered mature and robust.

In addition, an innovative process for the vitrification of solutions containing a broader range of fission products, with higher throughput, in an induction crucible less susceptible to corrosion[176] using the “cold crucible vitrification process”, has been jointly developed by CEA and Areva. Since 2013, use of the cold crucible technology has started for the production of CSD-U vitrification packages of fission products from processing of spent “Umo” fuels (consisting of an alloy of uranium and molybdenum) used in the gas-cooled reactors and for which the cold crucible technology is essential, given the high molybdenum content.

In 2015, ASN authorised the use of the cold crucible technology for the vitrification of fission product solutions from the processing of spent fuels from pressurised water reactors.

Generally speaking, the benefit of the vitreous matrix lies first of all in the reduced volume obtained and its durability properties. With regard to the current standard glasses, predicting the long-term behaviour in geological conditions is based on the development of a mechanistic alteration model. Producing this model entailed understanding the alteration and fracturing mechanisms as a result of the internal irradiation and the disposal conditions.

4.2.2.2. Packaging of ILW-LL waste

Waste known as ILW-LL comprises numerous types of waste from components (other than fuels) subjected to a high neutron flux in the reactor, from processes linked to the recycling of spent fuels, solid technological waste from maintenance or decommissioning work on facilities, workshops and laboratories. To package these waste, various processes using a variety of blocking materials are deployed industrially or are in the process of being implemented. The producers are also carrying out R&D programmes, on the one hand to provide data to assess the behaviour of the package during the storage and repository operation phases (gas source terms, corrosion) and, on the other, to define the long-term performance in a geological repository.

Packaging of sludges

Bitumen was chosen as the material for encapsulating radionuclide co-precipitation salts, owing to its high binding capacity, its significant chemical inertia, its impermeability, its low solubility in water, its containment capacity, its moderate cost and, finally, its availability. To confirm its behaviour in the repository, the nuclear licensees and Andra ran a substantial R&D programme (2012-2015) to demonstrate the safety of the performance of the packages of bituminised sludges in a deep geological repository, more specifically with regard to the fire risk. Very significant additional data was also acquired with calculation of the radiolysis hydrogen source terms and the

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[176] The absence of contact between the molten glass and the cold metal guarantees that there is no corrosion of the crucible, despite the aggressive nature and temperature of the molten glass.

corresponding swelling, with a view to guaranteeing the physical integrity of the package during the repository operating phase.

The bituminisation process has today been almost entirely replaced by other processes. For example, a process known as drying-compacting of sludges resulting from processing by chemical co-precipitation of low and intermediate level effluents is under development for recovery of legacy sludges from the STE3 unit in La Hague.

R4 – CEA, together with Andra and the owners of bituminised waste, will be continuing to study the behaviour of bituminised waste packages (reactivity and ageing in particular) in order to acquire the scientific and technical data needed to assess their physico-chemical and thermal behaviour during the repository's reversible phase and beyond. If it so considers necessary, ahead of the studies, Andra provides CEA with information about the behaviour of the bituminised packages it wishes to obtain for preparation of the Cigeo safety case.

By 30th June 2017, CEA will submit a report describing all the available results.

By 30th June 2018, Andra will submit a report assessing the impact of these results on the conditions for acceptance of bituminised waste packages in Cigeo.

R5 – By 30th June 2018, CEA and Areva will submit a design report on the means of transport of bituminised waste packages.

R6 – CEA will be continuing R&D studies on methods of processing and packaging bitumen encapsulated waste (LLW-LL and ILW-LL) in particular combining chemical and thermal processes.

By 30th June 2018, CEA will submit a progress report on this work.

By 31st December 2019, CEA, Areva, EDF and Andra will submit a technical, economic and safety assessment report comparing the various modes of processing and packaging envisaged for the bituminised waste (geological disposal and alternative solutions). This study includes all the steps in management of the waste as well as the impact of the various choices on the design and sizing of Cigeo: transport, safety during storage and operating phase, environmental impacts, long-term radiological impacts.

Compacting

Since 2002, the hulls and end-pieces from fuel cladding removal have been compacted into pucks and packaged in stainless steel packages in the ACC unit in the La Hague plant. R&D work is being carried out at a European level on the dynamics of ^{14}C release from zircaloy cladding and metal elements during the disposal period.

Cementation

Cementation is the oldest and most widespread process for packaging of ILW-LL waste. It is used to block massive solid waste and metal waste which has been subjected to a high neutron flux in reactors, or technological waste, but also to encapsulate effluent concentrates or powder waste, such as the ion exchange resins used to process pool water. Cements offer a number of qualities, such as availability, access to a wide variety of formulations suited to numerous types of waste, reasonable cost, ease of use, good mechanical strength and high containment capacity.

The main progress in recent years concerns the behaviour of polymer material based technological waste. Ionising radiation leads to a process of radiolysis of the polymers, generating new molecular species. The R&D programmes which were started in 2006 enable a conservative operational model to be developed for hydrogen gas release, built around a radiochemical yields database from industrial polymers and a mathematical description of the physical processes of radiolytic degradation (radiation/materials specific to each type of emitter, energy deposition and energy absorption by the material).

In accordance with the request made in the 2013-2015 PNGMDR, Areva submitted a study in 2015 on the progress of characterisation of ILW-LL waste produced before 2015 and on the packaging design programmes for these waste[177]. For each of the retrieval operations in progress, the Areva study presents the general approach to the development and design of ILW-LL packages compatible with Cigeo. For each of the families, a production baseline was or will shortly be submitted. This packaging baseline is examined by ASN, although without prejudice to the consent that will need to be given by Andra for its acceptance in the repository. With a view to developing a package for Cigeo, R&D programmes are being carried out in three main areas: (i) R&D on the package design choice, based on the various technologies (ii) R&D aiming to demonstrate package integrity during the storage and the repository reversible operations phases and, finally, (iii) a third part concerning the long-term behaviour in geological disposal conditions during the gradual resaturation phase, up to complete resaturation of the site. For this latter, the responsibility for the demonstration is shared by the producer, which focuses on defining the source terms or release models and Andra, which focuses on demonstrating the behaviour in the presence of the repository materials. The definition of a package is thus the result of an optimum trade-off between all these points.

In accordance with the request made in the 2013-2015 PNGMDR, CEA submitted a study in 2015 on the progress of characterisation of ILW-LL waste produced before 2015 and on the packaging design programmes for these waste[178]. The CEA study presents:

- the inventory of organic material contained in the waste in the ILW-LL packages;
- the process to assess the nature and quantity of the gases produced by degradation of the waste and the available experimental results;
- the work to determine the nature and quantity of the hydrosoluble degradation products HDP[179] formed by degradation of the waste and the studies carried out on the complexing capacity of the HDP formed;
- the lessons learned from the HDP transfer and adsorption experiments on the argilite on the Bure site.

ASN asked that this study be continued and finalised on the basis of several recommendations made in its letter to CEA on 25th February 2016[180].

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[177] The report submitted by Areva is available on the websites of ASN and the Ministry responsible for energy:

- http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015 ;
- http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

[178] The report submitted by CEA is available on the websites of ASN and the Ministry responsible for energy at the above-mentioned addresses.

[179] More specifically owing to phenomena of complexing with the radionuclides, hydro-soluble degradation products (HDP) are liable to modify their migration in the repository.

[180] ASN letter to CEA dated 25th February 2016 (reference: CODEP-DRC-2016-008380), available on the ASN website: http://www.asn.fr

R7 – CEA will be continuing its studies on the characterisation and packaging of ILW-LL waste produced before 2015 on the basis of the recommendations made in the above-mentioned ASN letter of 25th February 2016 and as related to the preliminary version of the acceptance specifications mentioned in R2.
On the basis of the hierarchy of studies to be carried out, CEA will provide a calendar for the performance of the envisaged R&D programme.

Vitrification

In 2010, Areva implemented a process for the production of standard vitrified waste packages of intermediate level rinsing effluents, known as CSD-B, produced by the operations to prepare for decommissioning of the UP2-400 plant. Owing to the radiological nature of the effluents processed, the CSD-B packages fall into the ILW-LL category. At the same time, long-term behaviour studies were carried out to estimate the performance of these glasses with a relatively low radiological inventory in cement vault disposal conditions (unlike the case of the HLW vaults, a cement liner is planned for the ILW-LL vaults).

Incineration/vitrification process

Following the abandonment of compacting of organic waste rich in alpha emitters, which ASN considered did not offer sufficient guarantees for long-duration storage or for disposal, an innovative incineration/vitrification process, called PIVIC, aiming to process and package the waste in a single step is being examined. The principle consists in placing the waste in an oven and incinerating it, or melting metal waste, using a plasma torch over a bath of molten glass. The resulting ashes are incorporated into the glass and the molten metal finds itself at the bottom of the crucible. The waste primary container thus consists of a metal phase and a vitreous phase. This process combines several processes, in particular plasma torch incineration, vitrification, melting by induction and treatment of the gases. More particularly within the framework of the 2013-2015 PNGMDR, Areva submitted an interim report presenting the programmes to study the feasibility of processing technological waste (metal and organic) contaminated by alpha emitters. Its demonstration is based on an R&D programme including the design and performance of tests on mock-ups.

R8 – Together with CEA and Andra, Areva will be continuing work to develop the incineration/vitrification process, called PIVIC, aiming to package ILW-LL organic waste rich in alpha emitters, for commissioning in about 2030. Before 31st December 2018, Areva will provide an interim report on this work.

Processes to be defined

Structural waste such as magnesium cladding from spent gas-cooled reactor fuels and powder waste from the processing of spent gas-cooled reactor fuels stored in Marcoule must be packaged before 2030 in accordance with the time-frame defined in Article L. 542-1-3 of the Environment Code. New types of packaging must be defined for these waste.

R9 – Before 31st December 2017, CEA will transmit its system for the retrieval of structural waste such as magnesium cladding from spent gas-cooled reactor fuels and powder waste from the processing of spent gas-cooled reactor fuels stored in Marcoule, along with the development plan for the corresponding packaging units, plus a schedule demonstrating compliance with the time-frame defined in Article L. 542-1-3 of the Environment Code.

4.2.3 Partitioning and transmutation of the minor actinides

The 28th June 2006 Act confirmed the interest of research on storage and partitioning and transmutation, underlining the fact that they are a complement to deep geological disposal. This research is coordinated by CEA, in order to *"assess the industrial prospects"* of the corresponding technologies (generation IV fast neutron reactors, accelerator-driven systems) and to prepare for start-up of a prototype facility by about 2020.

Partitioning and transmutation.

Utilising uranium oxide based fuels (UOx) or fuels based on a mixture of uranium and plutonium oxides (MOx) in a reactor leads to a change in their chemical and isotopic composition owing to the various fission and neutron capture reactions. The fission reactions produce fission products: radioactive elements, divided into two families centred on elements with a mass of 100 and 140 (lanthanides family), which mainly emit beta and gamma radiation. The neutron capture reactions of uranium and plutonium mainly produce the actinide elements: neptunium (Np), americium (Am) and curium (Cm), known as the "minor actinides".

The target elements for the partitioning and transmutation strategy are the minor actinides (Np, Am, Cm), provided that a policy of recycling or even multi-recycling of the plutonium is implemented beforehand. The partitioning then transmutation of long-lived fission products is not technically possible.

Partitioning and transmutation cannot be applied to all radionuclides and does not allow total destruction of the elements, so it does not obviate the need for deep geological disposal. It must thus be seen as an avenue for the possible optimisation of high level waste management.

Benefits of partitioning and transmutation

As the minor actinides are not mobile in the clay repository concept selected in France, they are almost totally confined in the near field and do not contribute to the radiological doses at the outlet (in a normal or altered evolution scenario – excluding the inadvertent intrusion scenario). However, as the plutonium has been extracted, they represent the majority component of the intrinsic radiotoxicity inventory of the ultimate waste in the medium and long-term (see figure below)[181], as well as the main source of its heating power in the first centuries of its gradual decay.

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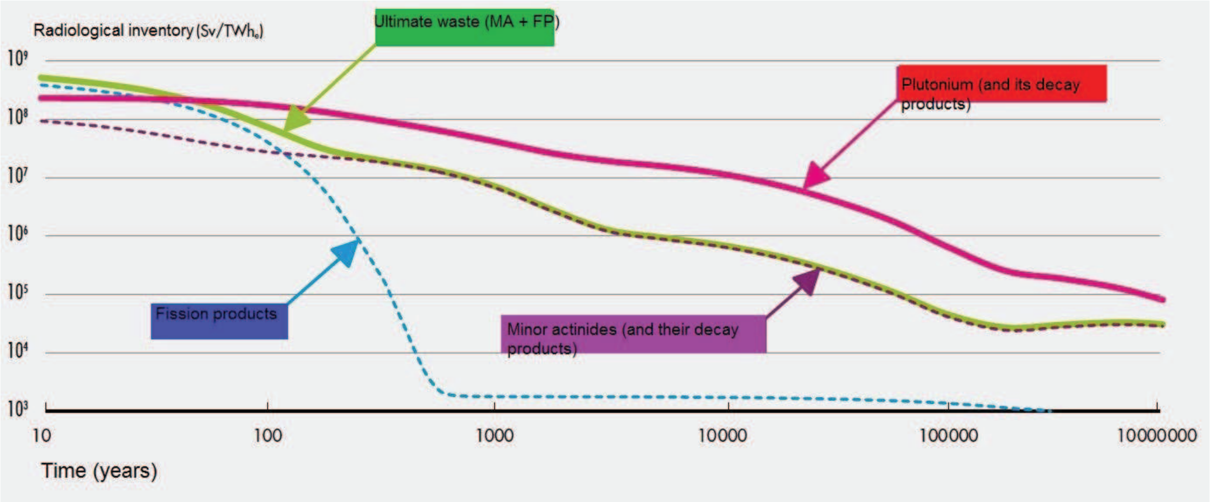
[181] After three centuries, nearly 99% of the residual radiotoxicity of the vitrified waste currently produced is due to the presence of americium, curium and their decay products.



Evolution over time of the inventory of radiotoxicity by ingestion of various components of a spent fuel (UOX 45GWd/t)[182]

Various implementation scenarios for partitioning and transmutation

In order to compare the different partitioning and transmutation options, scenario studies were carried out, calculating the impact of the scenarios on the ultimate waste management, considering various criteria such as: the volume of waste, the radiotoxicity inventory, the radiological impact of the repository and the heating power of the waste. With regard to this last criterion, the residual heating power calculations for high-level packages containing ultimate waste from the processing of UOx and MOx fuels indicate that after 100-120 years, the residual heating power of the HLW packages comes mainly from the ^{241}Am isotope with a radioactive half-life of 433 years. The main contributors to the short-term thermal component are the ^{137}Cs and ^{90}Sr fission products with a half-life of about 30 years and the ^{244}Cm with a half-life of 18 years. Thus, by envisaging the prior use of a sufficient period of storage before disposal, in order to reduce the short-term thermal contribution of the Cs, Sr and Cm elements, the transmutation of americium would allow a significant reduction in the medium to long-term thermal component of the waste packages and thus the ground footprint of the disposal site.

Of the Np, Am and Cm actinides, americium is thus the priority target for the partitioning and transmutation scenarios: the transmutation of americium is liable to provide far greater gains than with the other minor actinides, while avoiding the considerable constraints involved in the management of elements such as curium. All of the studies on partitioning and transmutation of the minor actinides carried out since 2012 only concerned americium.

The partitioning and transmutation of americium consists in selectively extracting it from the spent fuels so that it can then be transmuted in fast neutron reactors (in other words, through fusion to obtain elements with a shorter half-life, which can only be efficiently done in fast neutron reactors).

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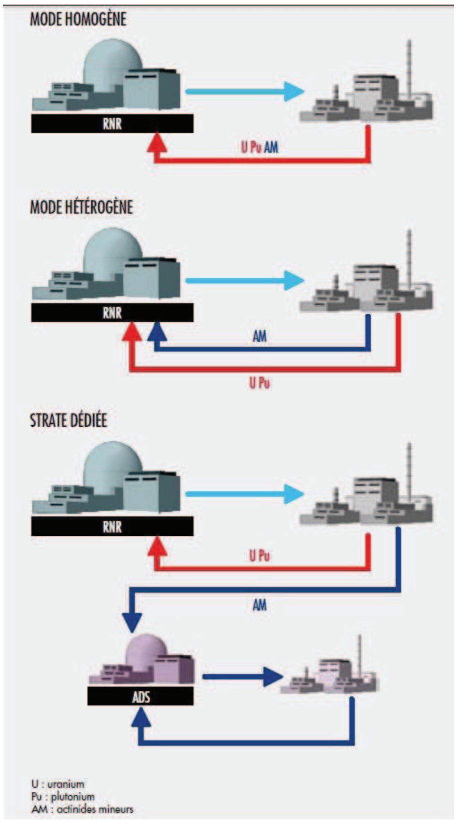
[182] This figure is taken from the report "Advances in research on the partitioning and transmutation and multi-recycling of plutonium in fast neutron reactors" submitted pursuant to the 2013-2015 PNGMDR and available on the websites of ASN and the Ministry responsible for energy:

- http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015 ;
- http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

Several options can be envisaged for this separation-transmutation (see figure below):

- homogeneous mode transmutation: the americium (or more generally, the minor actinides) is transmuted by "diluting" it in the fuel of power generating reactors (this leads to a content of about 1% by mass of heavy atoms);
- heterogeneous mode transmutation: the americium is transmuted in power generating reactors, in a more concentrated form in a limited number of "dedicated fuels"; one particularly interesting option would appear to be recycling in the form of uranium "blankets" charged with americium – AmBB[183] – (with a content of about 10% for a fleet consisting mainly of FNR) placed around the periphery of the core;
- transmutation in a "dedicated system", in a "dedicated layer" of the fleet; this is the option of transmutation in accelerator driven systems (ADS), which would manage the americium or, more generally, the minor actinides, completely separately from the uranium and plutonium management cycle.



Different minor actinides transmutation options [184]

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[183] The terms MABB for Minor Actinide-Bearing Blanket and AmBB for Americium-Bearing Blanket are used.

[184] This figure is taken from the report "Advances in research on the partitioning and transmutation and multi-recycling of plutonium in fast neutron reactors" submitted pursuant to the 2013-2015 PNGMDR and available on the websites of ASN and the Ministry responsible for energy.

Partitioning and transmutation prospects

Based on the progress made in the research on partitioning and transmutation, the 2015 report[185] from the national review board for research and studies on radioactive materials and waste (CNE2) recommended active continuation of research in this field of study so that progress could be made to improve the reliability of the processes which would be implemented as and when necessary.

However, more particularly in the light of the gains which could be hoped for from the transmutation of the minor actinides in terms of safety, radiation protection and waste management, the ASN opinion of 4th July 2013 considered "that the partitioning and transmutation possibilities for long-lived radioactive elements should not be a decisive criterion in the choice of the technologies examined for the fourth generation. The various reactor technologies studied should be more particularly compared from the viewpoint of the potential for reinforcing the protection of the interests mentioned in Article L. 593-1 of the Environment Code by comparison with the third generation EPR type reactors". These terms were recalled in its opinion of 25th February 2016, in which it added that "nuclear safety or radiation protection cannot on their own justify the continuation of studies on partitioning and transmutation."[186]

R10 – CEA coordinates the research into the partitioning and transmutation of long-lived radioactive elements, together with the other research organisations. In this respect, before 31st December 2018 and together with EDF and AREVA, it draws up a study programme which could be carried out in the prototype mentioned in 1° of Article 3 of the 28th June 2006 Act, in order provide a representative scale demonstration of the ability of the proposed technologies to multi-recycle the plutonium contained in the spent MOx fuels from water reactors using depleted uranium; stabilise or reduce the plutonium inventories by increased consumption of this substance and transmute the americium.
In this programme, CEA will present the radioactive waste produced by these technologies and the fuel cycle facilities which would be needed to run these demonstrations.

R11 – In order to clarify the possible initial state at the time of a potential large-scale deployment of fast neutron reactors, CEA is required, before 30th June 2018, to submit inventory forecasts of radioactive materials and waste present in the spent fuels which would be produced by the French NPP fleet in various scenarios, for between 2016 and 2100, more particularly following on from those studied with EDF and Areva in accordance with the 2013-2015 PNGMDR and including a scenario in which the future fleet would not be made up of fast neutron reactors.
In this study and together with Andra, CEA will also present an estimate of the total footprint of these radioactive substances in a deep geological repository.

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[185] This CNE2 evaluation report (n°9) is available on the CNE website: https://www.cne2.fr/.

[186] The ASN opinions of 4th July 2013 (2013-AV-0187) and 25th February 2016 (2016-AV-0259) on the management of high level and intermediate level, long-lived waste, are available on the website http://www.asn.fr, heading « les actions de l'ASN », « la réglementation », « bulletin officiel de l'ASN », « avis de l'ASN ».

4.2.4 Storage of HLW and ILW-LL waste

Even if long-duration storage is not an acceptable final solution for the management of radioactive waste, storage is essential pending the commissioning of the Cigeo disposal project, to enable certain waste to cool and then to support its industrial operation which will develop in stages, associated with an open and gradual decision-making process. Furthermore, if operations to remove emplaced packages were to be decided on for reversibility of the repository, storage facilities would in principle be needed.

Storage studies and research

The 28th June 2006 programme Act entrusted Andra with coordinating research and studies on the storage of HLW and ILW-LL waste. Their aim is to complement reversible disposal. The law required that they be carried out so that new storage facilities could be created or the existing facilities modified, no later than 2015, to meet the needs identified by the PNGMDR, more particularly in terms of capacity and duration.

Jointly with Andra, Areva thus integrated certain advances into the design of the extension of the HLW waste storage facility on the La Hague site, commissioned in 2013. This enables a longer operating life for this facility to be envisaged.

Although Andra supervised the performance of these studies, collaboration between Andra and other nuclear licensees (Areva, CEA and EDF in particular) needs to be developed to build on experience feedback from the design, construction and operation of existing storage facilities and to reinforce the complementarity between the facilities operated by the waste producers and the future deep geological repository.

In early 2013[187] Andra submitted a report on all the research and studies carried out. This report more particularly presented a survey of future storage requirements, the exploration of the complementarity between storage and disposal, studies and research on engineering and on the phenomenological behaviour of the warehouses and a review of innovative technical options. From 2013 to 2015, Andra conducted more in-depth studies into storage concepts linked to repository reversibility. This concerns hypothetical future installations which, if necessary, would accept packages removed from the repository. For such installations, Andra looked for versatility which would allow simultaneous or successive storage of packages of various types in their primary form or placed in a disposal over-pack.

Starting from the results of the research and studies, Andra issued recommendations in 2014[188] for the design of future installations to complement disposal. These recommendations also benefited from industrial experience feedback and the continued research on the durability of materials and

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[187] This Andra report "Summary of studies and research on storage (high level and intermediate level, long-lived radioactive waste) (reference CRPADPG130001.B) is available on the CNDP website: http://cpdp.debatpublic.fr/cpdp-cigeo/docs/decisions/rapport-2012-andra-entreposage.pdf

[188] Andra report: "Recommendations for the design of storage facilities to complement disposal." submitted pursuant to the 2013-2015 PNGMDR, is available on the websites of ASN and the Ministry responsible for energy:

- http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015 ;
- http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

on monitoring and surveillance systems. They more particularly deal with the provisions favourable to the durability of the installations (up to a hundred years), their monitoring and surveillance and the design of the storage facility necessary to allow repository reversibility.

At the present stage, generic studies into storage concepts to complement disposal will provide no further significant advances. Additional studies could be carried out for storage facility projects run by the licensees.

In any case, the studies carried out by Andra and experience feedback have enabled the following guidelines to be identified:

- Adopt significant design margins for the civil engineering part of the facilities with respect to the anticipated duration of waste storage and the resistance to external hazards. For modular warehouses, the increase in the size of the facilities as a result of adding extensions should be taken into account in the design safety assessment;
- Opt for a simple, modular architecture, the use of passive systems (ventilation by natural convection in particular) and adapt the number of static containment barriers to the nature and condition of the packages stored;
- At the design stage, define measures – appropriate to the materials of the radioactive waste packages – able to control the ambient storage conditions in normal, incident and accident operating situations (temperature, relative humidity, radiolysis hydrogen concentration, etc.) and able to maintain the first static containment barrier provided by the package;
- At the design stage, define the systems necessary for monitoring and processing of potential problems with the civil engineering structures, the facility's equipment and the waste packages; in particular focus on installing equipment in the facility capable of repackaging degraded containers;
- Take steps to ensure that a recorded trace (memory) of the storage facility and any modifications made to it is preserved, up to its delicensing and, for the duration of storage, guarantee unambiguous identification of the radioactive waste packages and the recording and archival of the information necessary for subsequent management of the waste they contain.

R12 – The licensees shall demonstrate that the above-mentioned recommendations have been taken into account in the design of new storage facilities or, for existing facilities and whenever applicable, on the occasion of the periodic reviews.

In its study submitted in 2013, Andra states that it has ceased research on near-surface storage facilities owing to the greater complexity – in particular linked to management of groundwater and ventilation in the case of exothermal waste – of civil engineering monitoring and surveillance (limited accessibility to the outer surface of the structures in contact with the rock) and reduced flexibility. The level of technical detail in the document submitted by Andra does not however allow a conclusion to be reached on whether the decision to definitively abandon the near-surface storage facilities design option is a pertinent one.

R13 – Before 31st December 2017, Andra shall specify the technical data on the basis of which it decided to definitively abandon the near-surface storage facilities design option.

Survey of storage capacity requirements on the radioactive waste production sites

Two types of waste package storage solutions are deployed industrially: modular storage facilities with a design incorporating the ability to build extensions as and when needed, without interrupting operations, and storage facilities with a predetermined capacity for a specific population of waste packages.

The packages of HLW and ILW-LL waste must all be stored in dedicated facilities. Within the framework of the 2013-2015 PNGMDR, and after presenting the inventory of HLW and ILW-LL waste packages intended for Cigeo[189] as at the end of 2013 and the status of the existing storage locations, the producers more specifically analysed the core data enabling storage requirements for waste packages[190] to be identified. To do this, only four examples representative of the various package families were selected by the licensees:

- packages of vitrified HLW waste stored in E ES EV type disposal facilities on the Areva site at la Hague,
- bitumen packages in the EIP on the CEA Marcoule site,
- cemented ILW-LL packages from CEDRA on the CEA Cadarache site,
- the C1PG packages of ILW-LL waste for the future ICEDA storage facility on EDF's Bugey site.

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[189] Data in PIGD rev. D June 2014.

[190] The joint CEA, Areva and EDF report: "Management of HLW/ILW-LL waste: storage requirements for packages intended for the planned Cigeo repository" submitted pursuant to the 2013-2015 PNGMDR is available on the websites of ASN and the Ministry responsible for energy:

- http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015 ;
- http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

The results of this analysis are shown in the following summary table.

Topic	*Sub-topic*	**EVLH Vitrified waste packages**	**EIP Bitumen packages**	**CEDRA MI packages**	**ICEDA C1PG packages**
Existing storage facilities	*Current storage facility*	Yes, can be extended by pits	Yes: Extendable vault	Yes: Extendable tranche	Under construction
	Storage site	La Hague	Marcoule	Cadarache	Bugey
	Industrial commissioning date	R7 1989, T7 1992, E-EV-SE 1997, E-EV-LH pit 30 2013	2 000	2 006	2 018
	Planned operational duration	75 to 100 years	50 years	50 years	50 years
	Storage capacity	R7 4,500 spaces, T7 3,600 spaces, E-EV-SE 4,428 spaces, E-EV-LH pit n°30 4,199 spaces	6,000 drums/vault	4,000 FI packages/building 1500 MI packages	4,000 m^3
Storage management	*Filling duration / incoming traffic*	5 years per vault	3 years/vault	10 years/Tranche	-
	Removal duration / outgoing traffic to Cigeo	5 years for a vault once Cigeo up and running	3 years/vault	≤ 5 years/building	For ILW-LL waste, between 100 and 150 packages / year as of 2055 (according to PIGD vD)
	Need for an extension/ new facility	Every 5 years	5-6 in 2025	T2 after 2028	Not at present necessary
Extension possibilities	*Additional capacity*	E-EV-LH vault n°40 4,212 spaces in 2017, then the equivalent every 5 years	7 to 16 vaults of 6,000 drums	Building / tranche (4000 FI packages and 1500 MI packages)	One half-hall in ICEDA
Construction time	*Forecast time to build an extension/ new storage facility*	3 years	4 years	5 years (tranche of several buildings)	2 – 5 years
Engineering time	*Duration of design studies, extension application*	4 to 5 years (without article 31 and without public inquiry)	2 years	3 years (decree)	-
	Duration of design studies and application for a new facility	6 to 7 years (with article 31 and with public inquiry)	-	-	~ 8 years including administrative authorisations[191]

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[191] Operating experience feedback also shows that the time needed from the first design steps up to actual commissioning, is about 10 to 15 years.

The producers state that a complete analysis could only be applied to all the HLW and ILW-LL waste packages once the schedule of package deliveries to Cigeo has been updated.

Areva however makes the following clarifications with regard to its storage requirements on its La Hague site:

- concerning vitrified packages, the R7, T7 and EEVSE storage facilities represent a total capacity of 12,528 packages, which is saturated. The EEVLH pit 30 storage facility has a capacity of 4199 spaces able to take vitrified packages until 2017. In 2017, EEVLH pit 40 will be commissioned to take 4212 packages until 2021. As of this date, Areva is examining the feasibility of extending pit R7. Areva anticipates submitting the extension authorisation applications for R7 in 2016;
- concerning compacted packages, the ECC storage facility with a capacity of about 20,900 spaces will be saturated in 2020 at the earliest. Areva currently envisages submitting an extension authorisation application in 2017;
- concerning cemented packages, no short-term saturation of the total storage capacity for these packages (12,046 spaces) is anticipated. Areva envisages storing the CBF-C'2 packages in EDT-C as of 2018, and transferring the drums of hulls and end-pieces (1518 FCE) from EDC-B and C to DE EDS in 2019 to free up space for the CBF-C'2. To do this, Areva submitted an authorisation application in December 2015;
- concerning bitumen drums, the C5 packages and the alpha waste, there will be no short-term saturation of the overall capacity of the STE3 and DE EB storage facilities (47,000 spaces). The bitumen drums are currently stored in three vaults of the S building in STE3. Areva envisages storing the C5 packages in two vaults of the ES building of DE EB when they are produced. In addition, the primary drums of alpha waste on the La Hague site are currently stored in two vaults of the ES building in DE EB. Areva envisages using a third vault as of 2019 for storage of the remaining alpha drums. Areva intends to submit authorisation applications in 2018. In order to be able to use a fourth vault for the alpha drums and eventually for the PIVIC packages, Areva envisages transferring the bitumen drums from one of the three vaults to the other two. To do this, Areva intends to submit an authorisation application in 2018.

The study so far submitted by the producers remains incomplete. In this respect:

- the inventories of radioactive waste must be updated and should be permanently kept up to date;
- the analysis of future storage requirements should concern all the families of HLW and ILW-LL waste and not be limited to 4 families of waste intended for Cigeo.

R14 – The producers of HLW and ILW-LL waste will annually update the availability status of the storage capacity for HLW and ILW-LL for each waste family and identify the future storage capacity requirements.

R15 – For the purposes of the first exercise, the producers of HLW and ILW-LL waste will submit future storage requirements before 30th June 2017, covering at least the next 20 years, for all families of HLW and ILW-LL waste, in accordance with recommendation R14.

For technico-economic reasons, the strategy adopted by the licensees for the management of the storage facilities consists in adjusting the storage capacity and the calendar for the construction of new storage facilities or extensions in the case of modular design facilities (as is for instance the case on the La Hague site for vitrified waste) according to the production streams and the waste filling and removal from storage time-lines.

Although it is legitimate to programme the extension of storage capacity as and when waste is produced, the fact of relying on storage removal hypotheses nonetheless requires the adoption of margins, failing which there could be a risk of premature saturation of the facility in the event of unforeseen circumstances.

Uncertainties remain with regard to the commissioning calendar for a deep geological disposal facility, the delivery time-lines to be decided on and authorised and, finally, the acceptability of certain waste packages in the facility, were it to be authorised. The observation made by ASN in its opinion of 16th May 2013[192]: *"in their studies, the waste producers concerned must adopt the necessary margins to cover any unforeseen circumstances in the downstream routes, so that sufficient storage capacity for the waste is obtained in good time, prior to its disposal in the deep geological repository"* is still valid today.

Recent operating experience feedback (DIADEM and ICEDA facilities) also shows that the time needed to create new storage facilities, from initial design up to commissioning, is about 10 to 15 years.

R16 – The producers of HLW and ILW-LL waste must adopt significant time margins for performance of the design studies, construction and obtaining the administrative authorisations for new storage facilities, to ensure that the necessary storage capacity is available.

R17 – To verify the robustness of these margins, the producers of HLW and ILW-LL waste shall study the vulnerability of storage needs to any shifts in the Cigeo project development schedule.
This analysis should be able to identify any threshold effects in terms of future storage requirements or extensions to the operating life of ageing storage facilities.
These vulnerability studies more specifically include updating of the decommissioning strategies of the licensees.

R18 – Saturation of the storage facilities shall be monitored under the PNGMDR and the needs for new capacity, some of which have already been confirmed, shall be specified for at least the next 20 years.

I1 : Occupation of the storage capacity for all CSD-V vitrified packages on the La Hague site (expressed as available capacity over annual production of CSD-V)

I2 : Occupation of the storage capacity for all CSD-C packages on the La Hague site (expressed as available capacity over annual production of CSD-C)

I3 : Occupation of storage capacity for C1PG packages on the Bugey site

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[192] ASN opinion 2016-AV-0179 of 16th May 2013, in its consolidated version of 30th May 2013, on the documents produced by Andra since 2009 concerning the deep geological disposal project for radioactive waste is available on the website: http://www.asn.fr, heading « les actions de l'ASN », « la réglementation », « bulletin officiel de l'ASN », « avis de l'ASN ».

I4: Occupation of storage capacity for bituminised sludge packages on the Marcoule site

I6: Occupation of storage capacity for DIADEM packages on the Marcoule site

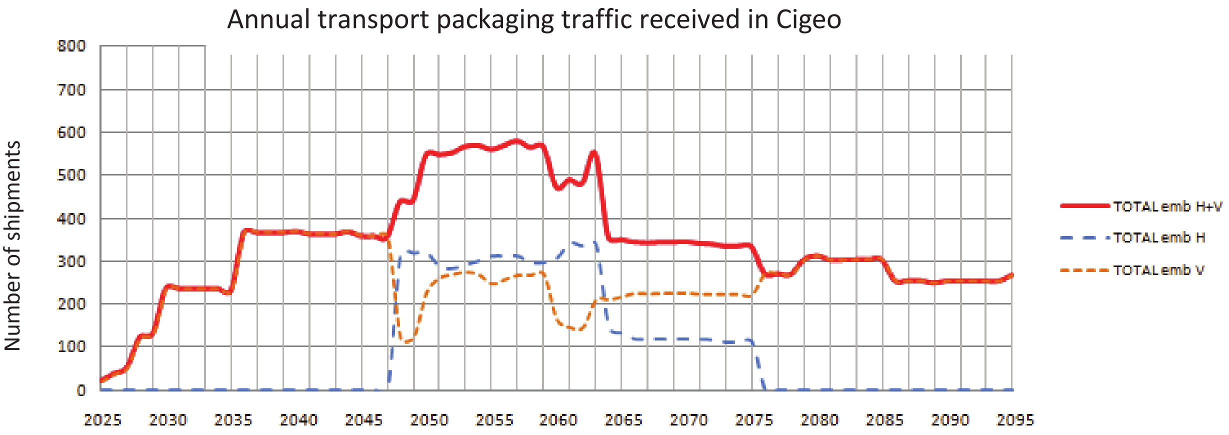
I6: Occupation of storage capacity for MI packages on the Cadarache site

I7: Occupation of storage capacity for FI packages on the Cadarache site

4.2.5 Adequacy of transport means for operation of the repository

The adequacy of the transport means for operation of the repository has been discussed by Areva, CEA, EDF and Andra. The producers are working together in the field of logistics upstream of disposal, which is their responsibility. More specifically, the field of transports is the responsibility of the consignors of radioactive substances.

The studies carried out on this subject are built around the waste management industrial programme (PIGD), defined by the producers, together with Andra, which describes the main hypotheses for scheduling deliveries of waste packages to Cigeo. The PIGD, which contains the input data for the Cigeo project design studies, in particular contains data about transport packagings, transport and operation modes, packaging capacity hypotheses and shipment traffic linked to the design of Cigeo.



Source: Waste management industrial programme defined by the producers, revision D, June 2014

The framework for the analysis by the waste producers of the adequacy of transport means for operation of the repository consists in performing a reverse planning based on experience feedback, to anticipate the availability of the packagings needed at the appropriate moment to allow shipment of the waste packages to Cigeo.

The guideline studies are based on the experience acquired with nuclear transport operations carried out by French industrial contractors, in particular the return shipment of waste belonging to Areva's customers from other countries, which are operations similar to those which will be needed for deliveries to Cigeo. By means of a standard reverse planning, this work identifies the design study programme needed to meet the identified milestones. The list of envisaged packagings and their mode of transport (road, rail, river, etc.) and operation (horizontal or vertical), is kept up to date in the PIGD.

The approach adopted by the producers is to propose transport solutions taking account of the best available level of knowledge of their primary packages and their operating experience feedback concerning the design, manufacture and operation of their fleets of radioactive substances transport packagings.

In 2015, the waste producers began transportability studies (pre-feasibility) which will continue for a number of years. The compatibility of the envisaged packagings[193] with the waste and package characteristics and with the storage removal and Cigeo reception installations will need to be verified.

Following these pre-feasibility studies, the design studies will begin.

The licensees consider that the service entry schedule for a new type of transport packaging is compatible with the anticipated date of receipt of the first packages in Cigeo. Application of the reverse planning to these types of waste packages showed that with the traffic levels as at the beginning of the package delivery schedule shown in the Cigeo preliminary design studies, the producers would have sufficient numbers of transport packagings for the first 10 years of operation of Cigeo. The first design studies identified will begin in 2017.

Reverse planning adopted by Areva, CEA and EDF

The producers drew up a standard reverse planning for the provision of waste package transport packagings intended for Cigeo, using the following main technical steps:

1) definition, design, development of appropriate transport packagings, then approval of these packagings by the authorities;
2) formal acceptance of the content by the destination sites and the authorities;
3) loading of packagings / inspections / shipment to Cigeo;
4) unloading of packagings in Cigeo / inspections / shipment of empty packagings to the producer sites.

The time needed for the definition studies, design and manufacture of the first-off packaging is at least 7 to 9 years before first service entry and can generally be broken down as follows:

- expression of requirement, pre-feasibility studies, design, drafting of safety files (safety options file then safety file) and the test programme (average of 3 to 5 years according to the complexity of the package model);
- assessment of safety file, issue of package model approval certificate (average of 2 years);
- manufacture of 1st first-off packaging (average of 2 years).

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[193] This does not rule out the possibility that packagings not at present envisaged might in the future prove to be more optimised solutions than those at present envisaged.

The waste producers intend to adapt the rate of packaging manufacturing to the needs (number of packagings /staggered service entry). If more packagings are required, which could extend the delivery lead-time by several years, they envisage utilising several production lines.

Application of producers reverse planning to Cigeo shipment needs

First of all the licensees gave priority to allocating approved or operational packagings to the waste packages with characteristics similar to those of packages actually being transported or for which transport is planned to other foreign routes/customers. The use of alternative packagings to those specified in the following paragraphs however remains possible given, on the one hand, the progress in the transport studies and the possible changes to the regulations and, on the other, the search for optimisation of certain Areva, CEA and EDF packagings.

At this stage in the studies, the producers checked that a sufficient number of packagings would be available for transport for the first ten years of operation of Cigeo, on the assumption that the initial design studies would take place in about 2017. For the following years, the producers see no particular difficulties, mainly owing to the remote nature of these shipments.

According to the waste producers, the initial transport requirement would be for the following packages:

- CSD-C from the La Hague site,
- CBF-C'2 from the La Hague site,
- packages of cemented hulls and end-pieces from the La Hague site,
- packages of 380 litre EIP bitumen drums (ILW-LL) from the Marcoule site and packages of 220 litre bitumen drums from La Hague,
- CSD-U from the La Hague site,
- packages of AVM and APM glass (HAO).

R19 – The schedule drawn up by the producers of HLW and ILW-LL waste for the first 15 years of operation of Cigeo shall be updated and supplemented to:

- **Incorporate a margin on the time necessary for the design studies, the approval studies and manufacture of the first packaging, based on operating experience feedback from the development of packagings in the past;**
- **Incorporate the time necessary for running dummy tests to verify the acceptability of the new packagings;**
- **Go beyond manufacture of the first-off packaging to ensure that the packaging manufacturing volume matches the need for transport to the repository.**

R20 – The producers of HLW and ILW-LL waste shall, before 31st December 2017, transmit an updated version of this study in accordance with recommendation R19.

Packagings selected by Areva, CEA and EDF and pre-feasibility studies

Case of waste packages to be shipped from the Areva site in La Hague

Concerning the packages of HAO CSD-U waste, Areva already has packaging models that it has been using for many years to return the CSD-V packages to its foreign customers. Areva thus selected the TN 28 VT, a packaging which is more generally the transport solution for all the CSD-

V, CSD-U, CSD-B type packages and standard HLW technological waste containers from the La Hague site. Areva envisages a regulations study aiming to guarantee the conformity of the packaging model with any changes to the regulations. Consequently, the pre-feasibility studies and the design studies will be far more limited than for most of the other packagings. No planning difficulty is observed at this stage.

With regard to the CSD-C packages, the chosen packaging is the TN ®843, as of the Cigeo pilot phase. This packaging obtained an approval certificate in July 2013 for the transport of CSD-C type packages for Areva's customers in other countries, similar to those that will need to be transported to Cigeo. Areva envisages a regulations study aiming to guarantee the conformity of the packaging model with any changes to the regulations. Consequently, the pre-feasibility studies and the design studies will be far more limited than for most of the other packagings. No planning difficulty is observed at this stage.

With regard to the ILW-LL waste placed in CBF-C'2 packages and in the other packages of cemented waste, the packaging chosen by Areva is the TN ®837 type. Areva has resumed the pre-feasibility studies for this packaging which had not been completed. Owing to its small capacity, which implies a need for significant packaging numbers and owing to the priority given to these packages in scheduling deliveries to Cigeo, Areva gives priority to the studies of this packaging.

With regard to the bitumen drums, a type TN ®833 packaging was chosen. Here again, its design had been started and then abandoned. Areva is thus resuming the transportability (pre-feasibility) studies for all the STE3 and STE2 type bitumen drums. This packaging is also selected at this stage for the C5 and PIVIC, which will be delivered at the end of the ILW-LL phase of the Cigeo project.

Finally, the TN ®28 transport packaging was chosen at this stage for hot CSD-V high level waste packages, as well as for all standard hot technological or HLW decommissioning waste from the La Hague site.

Case of waste packages to be shipped from the CEA Marcoule, Cadarache and Valduc sites

The case of packages of drums of ILW-LL bituminous waste from Marcoule is similar to that of packages of the same type to be shipped from the Areva sites: an approval application for a new packaging will be necessary.

The case of packages of vitrified waste from the Marcoule site is similar to that of the packages of vitrified waste from Valduc, technological waste from the Marcoule vitrification unit (AVM) and HLW radioactive sources: the envisaged packagings are those which obtained approval for the same type of package. A TN®28 VT type packaging was identified as being potentially usable for a few families, in terms of geometry and transportable mass. This concerns the containers of HAO vitrified waste from the AVM (for which delivery to Cigeo is planned during the pilot phase), vitrified waste from the APM (PIVER and laboratory vitrified waste), ILW-LL vitrified waste from Marcoule and Valduc, Atalante vitrified waste, containers of technological waste from AVM and HLW radioactive sources. The use of other packagings already approved, for example a TN ®843 type packaging, is also being examined.

With regard to the packages of ILW-LL waste to be delivered later on from the CEA sites:

- the hypothesis of use of a TN ®833 type packaging is also adopted for the 220 litre drums of magnesium waste from Marcoule (batches of 12) and the EIP drums of 380 litres containing cemented waste from Marcoule;

- for a few package families, the hypothesis of using an approved RD ®39 type is also adopted for packages of various waste, along with an IR 500 or IR 800 type packaging for waste in DIADEM storage containers. For most of the waste packages to be shipped from Cadarache (870 litre packages, 500 litre MI packages, 220 litre drums, etc.), transport solutions are currently being sought by CEA.

Case of waste packages to be shipped from the EDF sites

With regard to activated waste produced by the operation of PWR reactors and activated waste from the decommissioning of the first generation of EDF reactors, the packages will be produced within the activated waste packaging and storage facility (ICEDA), currently under construction on the Bugey site. EDF states that no design study for a transport packaging for these packages has yet been carried out owing to their remote shipment date and the probable changes to the transport regulations between now and then. The design studies for the transport packaging for these packages will be initiated so as to have approved and operational transport packagings within a time-frame compatible with the delivery schedule.

With regard to the activated waste to be produced by decommissioning of the PWR fleet today in operation, management of these waste will be defined in the decommissioning studies for the first PWR plant units. The design studies for the transport packaging for the package solution chosen will be initiated so as to have approved and operational transport packagings within a time-frame compatible with the delivery schedule.

Mode of transport up to the Cigeo facilities

The possibility of building a rail siding within the perimeter of the Cigeo repository is Andra's preferred option. This option is interesting from an industrial viewpoint, as it would avoid break bulks and could be put to good use by other traffic to the repository over the hundred-year operating period.

The public debate held in 2013 led to a certain number of opinions being expressed on this transport topic. As a result of these contributions and in the light of the shipment scenarios envisaged by the producers, Andra confirmed this preferred scenario of routing packages to Cigeo by rail, with access to the east of the site by building a connection to the existing network at Gondrecourt-le-Château in the Meuse *département*.

The facilities integrated into the repository will be described in the Cigeo creation authorisation application file.

R21 – Means of transhipment appropriate to the multimodal transports selected or envisaged shall be studied for Cigeo.

R22 – Before 31st December 2017 and together with Andra, the producers of HLW and ILW-LL waste shall submit an optimisation study of the various modes of transport to Cigeo being envisaged, in the light of the protected interests defined in Article L. 593-1 of the Environment Code. This study shall more particularly present the means of transhipment appropriate to the multimodal transports selected or envisaged.

4.2.6 Reversible deep geological disposal

Principle

Deep geological disposal of radioactive waste consists in placing packages of radioactive waste - without the intention of retrieving them - in an underground facility situated in a deep geological formation whose characteristics ensure the containment of the radioactive substances present in the waste. Such a disposal facility - unlike storage facilities - must be designed such that the long-term safety is ensured passively, that is to say without depending on human actions (such as monitoring or maintenance activities) which require institutional control, the durability of which cannot be guaranteed beyond a limited period of time. Lastly, the depth of the disposal structures must be such that they cannot be significantly affected by the expected external natural phenomena (erosion, climate change, earthquakes, etc.) or by "normal" human activities.

The deep geological disposal facility must also be reversible. This point is detailed in section 4.2.7.

Studies and research on deep geological disposal

Andra is carrying out studies and research on reversible disposal in the "Callovo-Oxfordian" argilites layer being investigated in the Meuse/Haute-Marne underground laboratory, so that a site can be chosen for the various installations and the repository design can be defined. The Laboratory's operating license was renewed in 2011, for a period running until 2030. Additional data on the progress made by the studies and research carried out in this laboratory are given in Appendix 3 to this PNGMDR.

Design of a deep geological disposal facility

The siting of the underground disposal facility is being examined in an area of 30 km^2, validated by the Government in 2010 after consultation of the stakeholders and on the advice of ASN, and which was the subject of in-depth reconnaissance work. The siting of the surface installations is being examined in two areas which would be operated simultaneously. One of these areas, between the two *départements*, on the Haute-Marne side, adjoining the Meuse, would more specifically be in charge of receiving and preparing the waste packages before they are sent to the bottom via a "ramp". The other area, which would be sited in the 30 km^2 geographical area mentioned above would be situated at the surface outlet from the vertical shafts and would be used in particular to evacuate excavated material and ventilate the underground facility.

The future deep geological disposal facility, called "Cigeo" would, subject to authorisation, be built and operated underground for more than a hundred years. This long duration implies the study of gradual development of the disposal structures in successive tranches which would be excavated and then commissioned one after the other (see section 4.2.7). During the construction and operation of the repository, this phase-based development should enable the steps adopted for the previous phases to be modified (more particularly concerning the design and operating procedures included in the authorisation application file). This should thus make it possible to take account of:

- experience feedback and scientific and technological advances (for example in the design, the construction, or the methods of filling the disposal vaults);
- any changes in the operating scenario as envisaged due to changes in terms of energy policy or industrial choices (leading for example to direct disposal of spent fuel), or societal

considerations (for example if the closure operations are postponed for a relatively long period of time);

The public debate and subsequent actions

A public debate on the Cigeo project was held by the national public debates commission (CNDP) from 15th May to 31st July and from 1st September to 15th December 2013.

As owner of the Cigeo project, Andra therefore presented the forecast inventory of waste to be disposed of, the siting proposals resulting from the Andra studies and consultation with the local stakeholders, a range of Andra proposals concerning reversibility and the results of the project preliminary designs (see below).

In March 2013, the High Committee for transparency and information on nuclear security (HCTISN) submitted its *"Preliminary report prior to the public debate on the Cigeo radioactive waste deep geological repository project*"[194], which was also included in the debate. This report presents the current situation with regard to questions about the inventory of radioactive waste considered for the Cigeo project, in the light of energy policy choices and to the transparency of the decision-making process which led to the definition of the Cigeo project, in particular by comparison with the other possible solutions for the management of high level waste. Among its recommendations, the HCTISN *"favourably welcomed ANDRA's proposal for a regular meeting with all the stakeholders, every 10 years, as part of the governance of the repository"*. It also considered that *"a major modification to the repository, such as that which, towards the end of the century, would involve the disposal of unprocessed spent fuels, would justify public participation going further than a public inquiry"*.

Although seriously disrupted by opponents to the project during the public meetings, the debate was a particularly intense one, with more than 76,000 visitors to the website, 1508 questions, 497 opinions, 154 "position papers", 24 more detailed contributions, 5 local assembly debates. The public debate minutes and report were published on 12th February 2014, along with the opinion of the panel of citizens resulting from the Conference of citizens organised by the CNDP.

The actions taken by Andra as a result of the public debate and following the deliberations of its Board in May 2014, comprise:

- four changes to the project: the inclusion of a "pilot industrial phase" prior to start-up of the facility; the implementation of a regularly revised master plan for operation of the repository; changes to the calendar; greater involvement in the project on the part of civil society;
- a proposal on reversibility: precise definitions for reversibility and retrievability; an incremental approach;
- three undertakings: guarantee safety above all; preserve and develop the host region; control costs.

The pilot industrial phase

Andra therefore announced that it will be implementing a pilot industrial phase before Cigeo makes the transition to routine operations. In addition to the tests performed in the underground laboratory, the purpose of this pilot industrial phase would in particular be to confirm the following in real conditions:

- the technical measures and steps taken to control the operating risks;

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[194] This report of 28th March 2013 is available on the HCTISN website: http://www.hctisn.fr.

- the performance of the industrial equipment;
- the ability to remove emplaced waste packages, during the course of recovery tests;
- the means and sensors for monitoring the repository;
- tests and demonstrators for the sealing techniques.

The transition to routine operation by Cigeo would then only take place once Andra had produced a report on the pilot industrial phase. The procedures for the transition from the pilot industrial phase to the routine operations phase have yet to be defined and regulated.

The "pilot industrial phase" planned by Andra should allow a gradual "ramp-up" of the repository and the production of in-situ demonstrators for running tests on a scale representative of the structures to be built.

R23 – The pilot industrial phase shall focus on acquiring data to confirm the facility's nuclear safety case. In this respect, Andra shall justify the quantity and nature of the packages necessary for the pilot industrial phase to be able to demonstrate the facility's ability to operate at an industrial disposal rate. During the "pilot industrial phase", the recoverability of the emplaced radioactive waste packages shall be demonstrated.

R24 – Andra and the radioactive waste producers shall take account of this "pilot industrial phase" when defining the time-lines of package delivery for disposal in the deep geological layer.

Preliminary designs

After about twenty years of studies and research, which assessed the scientific and technical feasibility of the disposal of HLW and ILW-LL waste in the Callovo-Oxfordian argilite layer, Andra initiated a study phase in 2010, aimed at producing a preliminary design for Cigeo. To do this, Andra – which will be the Cigeo licensee – selected a system lead contractor in January 2012 for the installations conceptual design, and then in 2013 added subsystem lead contractors for the preliminary designs.

An industrial conceptual design for all the Cigeo facilities was thus drawn up, corresponding to the inventory and waste package delivery schedule hypotheses of the waste management industrial programme (PIGD), defined by the waste producers in conjunction with Andra. At the same time, Andra drew up a preliminary definition of the disposal containers in which the primary containers delivered by the waste produced will be positioned before being emplaced in the disposal vaults. Following a value analysis and optimisation studies based on the conceptual design, Andra made fundamental design option choices in mid-2014.

In accordance with the project external review process initiated in 2011 by the Minister responsible for energy, the results of the conceptual study were submitted for review before the preliminary designs were launched. Interim conceptual design results were also examined by ASN, which in particular verified that the comments and recommendations it made in 2011 when examining Andra's "2009 milestone" file had been taken into account. ASN observed[195] that Andra had taken

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[195] See ASN letter to Andra of 18th November 2013 (reference CODEP-DRC-2013-033414), available on the ASN website: http://www.asn.fr.

account of its main recommendations about operating risks and considered that certain new design points would be such as to reinforce the operating safety of the facility. ASN also underlined that some options chosen by Andra will have to be justified in detail and that their impact on safety will have to be clarified in the future creation authorisation application file for the facility.

The preliminary design phase ran until 2015; the results were examined by another external review. At the same time, the PIGD will be updated in 2016 by the waste producers and Andra. A number of opportunities concerning the design of future installations were identified for the rest of the project, as part of the search for technical and economic optimisation, while meeting the expected level of safety. Some of these avenues are to be examined by Andra so that they could if necessary be implemented industrially as of the construction of Cigeo. Some also require studies, research and testing to be conducted by Andra before any industrial implementation: this preliminary work would be carried out in part in the underground laboratory and in part in a real Cigeo underground facility situation, more specifically during the "pilot industrial phase". In any case, the compatibility of these avenues with safety and reversibility requirements shall be guaranteed.

The detailed design studies are to continue until the end of 2017.

Continuation of other studies and research

These studies and research involve a significant experimental part in the Meuse/Haute-Marne underground laboratory, supplemented by tests on the surface to reproduce the conditions of the underground environment. They more particularly comprise continued in-situ scientific observation of the physical and chemical interactions between the argilites and the future repository structures. A particular effort was made concerning the construction methods used for the disposal vaults and drifts (excavation and lining) and the closure techniques. With regard to these latter, ASN in 2014 examined an *ad hoc* file submitted by Andra. ASN in particular observed[196] that *"Andra has on the whole upgraded the concepts of the closure systems and the related research programmes in a manner such that conclusive information on their feasibility should be obtained by the deadline for submission of the creation authorisation application. Therefore, at this stage, no major obstacle to the industrial feasibility of the reference concepts selected for the closure systems has been identified"*. It raises certain points still to be clarified for the continuation of studies and research.

In the studies that it carried out on the subject of reversibility, Andra considered that the disposal packages removed from the repository are not degraded. In these studies it would appear to be prudent to consider a situation in which the radioactive waste packages removed from the repository are degraded owing to their ageing in a disposal situation, but also to possible accident scenarios.

R25 – Andra will be examining the management procedures for degraded ILW-LL waste packages removed from the repository.

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[196] See ASN letter to Andra of 9th October 2014 (reference CODEP-DRC-2014-039040), available on the ASN website: http://www.asn.fr.

Evaluation of the cost of the Cigeo project

The procedure for evaluating the long-term cost of managing high level and intermediate level, long-lived waste is specified in Article L. 542-12 of the Environment Code: *"the agency [Andra] proposes an evaluation to the Minister responsible for Energy of the costs relating to the implementation of long-term management solutions for high and intermediate level, long-lived radioactive waste, depending on its nature. After receiving the comments from those liable to pay the additional taxes mentioned in V of Article 43 of the 2000 Budget Act (n° 99-1172 of 30th December 1999)*[197] *and the opinion of ASN, the Minister responsible for Energy finalises and publishes the evaluation of these costs"*. This evaluation is incorporated into the calculation by the nuclear licensees of the long-term management costs of their radioactive waste which, for reasons of safety or radiation protection, cannot be disposed of in surface or near-surface facilities. Thus, Article L. 594-1 of the Environment Code states that *"the licensees of BNIs make a prudent evaluation, […] more particularly taking account of the evaluation made pursuant to Article L. 542-12, of the management costs relating to their spent fuels and radioactive waste."*

After several years of work, Andra transmitted a costing file to the Minister responsible for energy[198] in October 2014. The Minister contacted the waste producers to obtain their observations, as well as ASN for its opinion. ASN issued its opinion on 10th February 2015.[199] Following this consultation, on 15th January 2016, the Minister responsible for energy determined the cost of Cigeo at 24 billion euros in the economic conditions of 31st December 2011, for the period 2016-2156. The ministerial order specifies that this evaluation will need to be regularly updated and at least at the key steps in the development of the project (creation authorisation, commissioning, end of pilot industrial phase, safety reviews). The documents concerning this decision are available on the website of the Ministry for the Environment, Energy and the Sea[200].

The evaluation of the cost, amounting to €25 billion$_{2011}$ includes the uncertainties inherent in any evaluation over such a long period (change in cost of labour, materials, energy and technological progress over 140 years, etc.), taking account of long-term technical optimisations and productivity efforts made by Andra, using a statistical approach. It constitutes an objective to be met by Andra in the management of its project and requires that the agency look for an approach to optimise it. Andra must thus remain mobilised for the main areas for optimisation identified, in compliance with the safety requirements set by ASN.

R26 – In accordance with Article 2 of the order of 15th January 2016 concerning the cost relating to the implementation of long-term management solutions for high level and intermediate level, long-lived radioactive waste, the cost of deep geological disposal must be periodically updated, more particularly on the occasion of the key steps in project development.

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[197] This concerns licensees of nuclear reactors (whether for the production of energy or for research) and spent nuclear fuel reprocessing plants, that is Areva, CEA, EDF and ILL.

[198] This two-volume file: "Evaluation of the costs relating to the implementation of long-term management solutions for high and intermediate level, long-lived radioactive waste" is available on the Andra website: http://www.andra.fr.

[199] ASN opinion 2015-AV-0227 of 10th February 2015, concerning the costs relating to the Cigeo project for deep geological disposal of radioactive waste is available on the website: http://www.asn.fr, heading « les actions de l'ASN », « la réglementation », « bulletin officiel de l'ASN », « avis de l'ASN ».

[200] These documents can be consulted at the following address: www.developpement-durable.gouv.fr/Le-processus-d-evaluation-du-cout.html.

4.2.7 The principle of reversibility

Presentation of reversibility

Although deep disposal helps mitigate the burden borne by future generations, the purpose of reversibility is to avoid them being permanently tied to the choices made by the current generation.

As provided for in the 28th June 2006 Act, Parliament has enshrined in law a clarification of the implementation of the reversibility principle for Cigeo. Act 2016-1015 of 25th July 2016 specifying the procedures for the creation of a reversible deep geological disposal facility for high level and intermediate level, long-lived radioactive waste gives a definition of reversibility applicable to Cigeo and specifies its implementation.

Reversibility is defined in it as *"the possibility offered to successive generations either to continue with the construction and then operation of successive tranches of a repository, or to reassess the choices previously made and change the management solutions."*

The law also states that *"Reversibility is implemented through incremental construction, the adaptability of the design and the flexibility of operation of a deep geological repository for radioactive waste, capable of incorporating technological progress and adapting to possible changes in the waste inventory, more specifically as a result of changing energy policy. It includes the possibility of recovering packages of waste already emplaced in the disposal facility, in accordance with procedures and over a time-frame consistent with the operating and closure strategy of the disposal facility. The reversible nature of a deep geological disposal facility must be guaranteed while ensuring protection of the interests mentioned in Article L. 593-1. The implementation of the principle of reversibility in a deep geological disposal facility is reviewed at least every five years, consistently with the periodic safety reviews provided for in Article L. 593-18."*

Andra proposes basing the practical implementation of the principle of reversibility on a range of tools that relate either to governance of the repository, or are more technical in nature.

The governance tools are as follows:
- continuous improvement in understanding the management of radioactive waste (more specifically by testing and special measurements inside the Cigeo facility during and after the pilot industrial phase, utilisation of monitoring data and the periodic drafting and publication of reports on the current state of knowledge);
- transparency and the transmission of information and knowledge;
- participation by society in the decisions made for development of the repository (for updating of the Cigeo operations master plan);
- oversight by the State and evaluators, under the supervision of Parliament.

The technical tools for project management used to support reversibility are:
- incremental development and gradual construction of the Cigeo installations;
- the flexibility offered by their operation (i.e. the ability of the facility to adapt to variations in the industrial programme – deliveries time-line, delivery traffic, partial closure date - without modifying the existing infrastructures or equipment and without the construction of any new structures);
- the adaptability of the installations (i.e. the ability to modify the installation to adapt it to new design hypotheses, for example changes in inventory, involving significant modifications to existing equipment or the construction of new structures);

- the retrievability of the waste packages emplaced.

These tools help with the decisions concerning radioactive waste management. More particularly, they enable the various possible choices to be maintained or opened up over a period of time. The cost of the technical measures adopted to allow reversibility (cost enabling the options to be offered to future generations) is integrated into the project. The present generations thus offer the following generations possibilities for modifying the disposal process in the future. However, if future generations were to decide to exercise this option, for example to modify the repository or remove packages, they would have to bear the cost.

Ahead of the Parliamentary debate on the reversibility of Cigeo, in July 2016, ASN issued an official position statement on the subject. In its opinion[201] of 31st May 2016, it underlines the fact that the principle of reversibility must entail a requirement for the adaptability of the installation, which must be able to change during its operation (for example, to adapt to inventory changes resulting from changes in energy policy) and a requirement for the recoverability of the packages, which it must be possible to remove from the repository for a given period in satisfactory conditions of safety and radiation protection.

Retrievability of radioactive waste packages

The recoverability option could potentially conflict with compliance with the safety and radiation protection objectives. To overcome this problem, Andra shall anticipate this recoverability exercise. In this respect, as of the design stage, it shall make provision for package recovery procedures and then management of the removed packages in surface facilities and shall demonstrate that these operations can be carried out in acceptable conditions of safety and radiation protection. It shall also adopt sufficient margins in the design of the facility to ensure that premature ageing of the structures will have no impact such as to rule out the possibility of recoverability. Finally, these recoverability requirements shall be incorporated into the radioactive waste package acceptance specifications.

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[201] ASN opinion 2016-AV-0267 of 31st May 2016 on the reversibility of radioactive waste deep geological disposal.

4.2.8 Adaptability studies (waste liable to be disposed of in a deep geological repository)

Reference inventory and reserves

Andra's design for Cigeo will ensure that the facility can be flexibly managed over time and that the design of the structures can evolve as they are built in successive tranches (see section 4.2.7). This flexibility and this adaptability will be detailed in the proposed operational master plan (PDE) to be submitted to the Government by the Agency following the preliminary design stage. On this basis, the PDE can be regularly updated during the hundred years of Cigeo operations and take account of any changes to the inventory of waste emplaced, in particular in the event of a change in energy policy.

As future licensee of a BNI, Andra is required to define the inventory of waste selected in order to draw up the creation authorisation application file. Article 17 of the Decree of 27th December 2013 setting the prescriptions of the 2013-2015 PNGMDR specifies that: *"without prejudice to the results of the examination of waste acceptance in the repository, the scope of waste to be considered by Andra for the disposal centre's creation authorisation application is specified, following the opinion of ASN and Andra, as necessary, by order of the Minister responsible for energy."* In this creation authorisation application file, Andra shall demonstrate the safety of disposal of the waste belonging to this reference inventory.

However, Article 542-1-2 of the Environment Code states that *"ultimate radioactive waste which, for nuclear safety or radiation protection reasons, cannot be stored on or near the surface, shall require deep geological disposal"*. As a precautionary measure, to ensure safety and transparency, Andra must conduct studies ahead of the Cigeo creation authorisation application to verify that the design of Cigeo does not preclude the possible acceptance of radioactive waste from the existing installations liable to require such disposal and which are not included in the reference inventory considered by Andra. These waste correspond to the reserves defined as such pursuant to Article 17 of the decree of 27th December 2013 setting out the prescriptions of the PNGMDR: *"The scope of the waste to be considered by Andra for the planned Cigeo disposal centre comprises an inventory and reserves. The reserves are a precautionary measure to cover uncertainties related more specifically to the industrial strategies or the implementation of new waste management routes."*

The typologies and quantities of the waste making up the reserves could be defined by the Minister responsible for energy. This broader approach should be able to cover any changes that may result from:

- future decisions regarding energy or industrial policy (for example, extension of operating lifetime or early closure of EDF power reactors) and reclassification of radioactive materials as radioactive waste (in particular the spent fuels from the EDF power reactors or those from naval propulsion and CEA's test and research reactors);
- the rerouting of waste for which acceptance in shallow depth disposal facilities is not guaranteed.

Studies on the reserves shall be enclosed with the Cigeo creation authorisation application file submitted by Andra. They shall include:

- an outline of the concepts selected for their disposal along with data giving a concise demonstration of the feasibility of a safety case;
- a demonstration that the design selected for the planned repository preserves the technical possibility of accepting them;

- data presenting any modifications to be made to the "support" facilities (ramps, access drifts, surface installations, ventilation, etc.) and their potential impact on the facility's safety case;
- the milestones of an R&D programme which would ensure that the complete safety case for their disposal is available in good time.

In any case, the waste which is included in the reference inventory (or part thereof according to the demonstration data provided) could be the subject of authorisation[202] on its own. Therefore an extension of the repository to all or part of the waste included in the reserves at the time of the facility's creation authorisation decree (DAC) application will always require a new complete authorisation procedure, including a public inquiry.

R27 – Before 31st March 2017, Andra will send the Minister responsible for energy a proposal of the types and quantities of waste to be included in the reserves.

In accordance with recommendation R7 in Chapter 4.1 (management of LLW-LL waste) and as a precaution, Andra and the producers may include certain LLW-LL reserves in the inventory to be submitted within the framework of the Cigeo creation authorisation decree application and in the associated safety case, but without the shipment of these waste to Cigeo being considered the reference solution.

Focus on studies concerning the disposal of spent fuels

The adaptability of Cigeo applies particularly to the case of a change in energy policy which would entail certain spent fuels no longer being processed and being reclassified as waste instead of materials. If the Cigeo authorisation application does not cover the direct disposal of non-processed spent fuels, which could entail submitting a new authorisation application (and thus holding a new public inquiry), Andra verifies that there is nothing in the project such as to preclude a possible development. To do this, it updates the feasibility assessment for direct disposal which it presented in 2005, taking account of subsequent changes to the available knowledge since that date.

A first study phase was devoted to updating the fundamental input hypotheses and data of the study: energy scenarios, fuel inventories and characteristics to be considered, fuel assembly packaging, scheduling and forecast delivery and disposal volumes. These hypotheses and data, defined in collaboration with EDF, were presented in the interim report submitted by Andra to the Government at the end of 2012.

In parallel with this work, Andra conducted a review of the spent fuel package and disposal vault concepts in the 2005 file. It sought consistency with the concepts developed for the Cigeo HLW waste.

The studies carried out in the period 2013-2015 mainly concerned fuels from the PWR reactors (MOx, URE and UOx). They cover different topics concerning science, criticality-safety and

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[202] For more details: ASN opinion 2013-AV-0179 of 16th May 2013, in its consolidated version of 30th May 2013, is available on the website: http://www.asn.fr, heading « les actions de l'ASN », « la réglementation », « bulletin officiel de l'ASN », « avis de l'ASN ».

engineering and show that the Cigeo project is compatible with the possible direct disposal of spent fuels. These studies led to the production of a summary report, which should be submitted in 2016.

In 2016 and 2017, Andra intends to complete these studies by looking in greater depth at particular technical points identified in the summary report and to extend them to include other types of spent fuels (CEA civil and military fuels, EDF/EL4 fuels, Superphenix fuels).

As mentioned in Chapter 2 (§2.2.2 and 2.2.3), EDF is constituting provisions for the cost involved in the storage and direct disposal of URE and MOx spent fuels. The latest cost evaluation of direct disposal of spent fuels dates from 2005.

For the other waste constituting the reserves, no evaluation is as yet available.

R28 – Andra regularly evaluates the cost of the disposal of the waste in the reserves.

R29 – With regard to Cigeo adaptability, Andra shall before 30th June 2018 send the Minister responsible for energy a cost evaluation for the direct disposal of spent fuels from the operation of NPP reactors or experimental reactors such as those used in naval nuclear propulsion. This evaluation shall be submitted to ASN for its opinion and to those in possession of these spent fuels for their comments.

4.3 Management of waste requiring specific work

Because of their properties, certain categories of radioactive waste require special management routes. This is in particular the case with waste containing tritium (tritiated waste) and used sealed sources, as well as radioactive waste from small producers unrelated to the nuclear power generating sector, which represents very small quantities.

Most of the tritiated waste cannot be accepted directly in the surface repositories owing to the high mobility of tritium through the media. The creation of new storage facilities by CEA over a period of about forty years offers a satisfactory solution in terms of short to medium term safety, pending its future transfer to disposal facilities. The work done to identify management solutions, initiated by the 2010-2012 PNGMDR, must be continued with regard to liquid and gaseous tritiated waste from the small producers unrelated to the nuclear power generating sector. **The 2016-2018 PNGMDR asks that by the end of 2017, CEA and Socodei, jointly with Andra, present an analysis of the comparison, for different types of tritiated waste, with regard to the protection of individual health, safety and the environment, of different tritiated waste management solutions, comprising storage, incineration (with or without prior storage) and direct disposal.**

Most used sealed sources are currently stored pending a final management solution. Owing to their concentrated activity and their potential attractiveness, only a small part of used sealed sources can be emplaced in the Aube repository. **The 2016-2018 PNGMDR requires that Andra examine the possibility of adapting the acceptance specifications for its installations, so that certain categories of used sealed sources can be accepted, while ensuring compliance with the requirements for protection of individual health, safety and the environment.**

As at the end of 2013, some other waste of various types, representing less than 0.3% of the volume of the waste produced, have no existing or planned disposal route, for example owing to only partial knowledge of their characteristics, to the particular physical or chemical characteristics of the waste, or to the absence of procedures for processing or packaging the waste prior to disposal. **The 2016-2018 PNGMDR requires that studies be continued on processing of this waste and sets a 2030 deadline for definition of a final management solution for all waste without a solution, produced before the end of 2015.**

4.3.1 Management of waste with no disposal route at present

The vast majority of radioactive waste has an existing management solution or is covered by a disposal route project currently being studied. **As at the end of 2013, less than 0.3% of the volume of the waste produced has no existing or planned disposal route**, for example owing to only partial knowledge of their characteristics, to the particular physical or chemical characteristics of the waste, or the absence of procedures for processing or packaging the waste prior to disposal.

To define appropriate management routes for some of these waste, studies are being carried out by a working group set up within the framework of the 2010-2012 PNGMDR and continued over the period 2013-2015.

In the first phase (2010-2012), this working group focused on adopting an exhaustive approach comprising a first task to consolidate the waste inventory currently without a disposal route, supplemented by a detailed examination of all of these waste. The inventory analysis thus carried out enabled the working group to identify three categories of waste referred to as "priority", because of the significant volumes they represent and the advantages to be gained from pooling reviews and studies among the producers. This concerns waste which requires processing and packaging before disposal, more particularly:

- waste containing free asbestos which cannot at present be accepted for disposal, given the high risk of it being returned to suspension and the requirements concerning the operating conditions and long-term safety scenarios,
- waste containing mercury, liable to volatilise or leach, depending on the physico-chemical conditions,
- certain organic oils and liquids which are not compatible with the acceptance specifications of the Centraco incineration installation.

The period 2013-2015 was devoted to continuation of this work. The studies carried out led to progress in the three areas detailed below.

4.3.3.1 Waste containing free asbestos

Specifications for the acceptance for disposal of asbestos-bearing waste in Cires and CSA are being finalised by Andra.

R1 – As soon as the updated Cires and CSA acceptance specifications for waste containing asbestos come into force, these waste can be removed from the list of waste "without disposal route" and declared in the appropriate management routes for the next submission to the National Inventory.

I1 – Monitoring of the quantity of asbestos emplaced in Cires and CSA in order to verify the compatibility of the repositories with the waste produced and to be produced.

4.3.3.2 Waste containing mercury

A process to stabilise metal mercury with sulphur has been tested on representative quantities of waste (up to 6 kg). This process produces a stabilised waste which should meet the Cires and CSA acceptance specifications. It is appropriate for the treatment of liquid waste containing metal mercury. For the other mercury waste, R&D studies are ongoing.

R2 – On the basis of the data supplied by Areva, CEA and EDF concerning the properties of the waste packages that could be produced using this metal mercury stabilisation process, Andra must by the end of 2017 confirm the acceptability from the standpoint of individual health, safety and the environment of the metal mercury stabilised by sulphur in the existing repositories and, as necessary, update the acceptance specifications of its installations to clarify the corresponding procedures.

R3 – Together with Andra, Areva, CEA and EDF must continue with studies of the processing/packaging processes for the other types of mercury waste for which no management route has yet been defined.

R4 – For the next submission to the National Inventory, Areva, CEA and EDF shall differentiate between waste containing metal mercury that can be treated using the above-mentioned process and the other mercury waste. The waste which can be treated would no longer be declared as "without disposal route" provided that the updated acceptance specifications for Cires and CSA are in force.

4.3.3.3 Organic oils and liquids

Three specific processes of varying technological maturity have been developed for treatment of organic oils and liquids according to their characteristics. A treatment process using mixing with polymers and already on the market is more specifically envisaged. This process produces a stabilised waste, the acceptance of which in Centraco and Andra's disposal facilities must be verified.

R5 – Areva and CEA, together with Andra or Socodei as applicable, shall by the end of 2017 provide a progress briefing on the development and implementation of the processes envisaged for treatment of organic oils and liquids, in particular:

- **continue studies on treatment by mixing with polymers and verify their acceptance in Centraco and Andra's disposal facilities. The management route selected (incineration prior to disposal, or direct disposal) shall in particular be substantiated in the light of the risks for safety, public health and the protection of nature and the environment;**
- **identify the inventory of waste which could be treated in the various processes developed by CEA and Areva and justify the management route chosen.**

R6 – EDF and Andra shall study the acceptability of the waste of this type in their possession in the routes set up by Areva and CEA.

R7 – The treatment and packaging of organic oils and liquids shall be carried out as early as possible and in any case as of implementation of the appropriate routes.

I2 – Percentage treatment of organic oils and liquid waste produced before 2015 (objective of 50% by 2025 and 100% by 2035).

In addition to the above-mentioned waste categories, Andra started work on the active parts of radiotherapy linear accelerators and cyclotrons used to produce radiopharmaceuticals or for research. These waste require characterisation work in order to assess their radiological properties, more particularly their inventory of long-lived β emitters, in order to be able to define their management route.

R8 – By the end of 2017, Andra shall provide a statement of progress concerning the management of activated waste from the small producers.

R9 – Conservatively, activated waste from the small producers must be identified and consequently declared in the category of waste without management route in the National Inventory.

I3 – a: Percentage of simulations and experimental studies for defining a tracer and the long-lived beta spectra of these waste (objective 100% in 2018)[203];
b: Percentage activated waste from the small producers produced before 2015 and covered by a final management route (objective of 100% in 2030).

Other waste without a management route produced in the nuclear facilities and which do not fall into the above categories represent small quantities and have varied physical or radiological characteristics. The studies aiming to develop treatment processes to ensure acceptance in the repository are presented within the framework of the waste management strategies of the licensees. These documents are periodically examined by ASN and ASND.

R10 – Progress concerning the definition of management routes will be presented during a meeting of the PNGMDR working group.

I4 – Percentage of waste without management route produced before 2015 and covered by a final management route (objective: the definition of a final management route for all the waste without a disposal route produced before the end of 2015 is expected by 2030).

4.3.2 Management of waste containing tritium

Most of the tritiated waste produced in France is operating and decommissioning waste linked to CEA's military applications, with the rest coming from small producers outside the nuclear power sector, primarily as a result of research or from the pharmaceutical and hospital sector, but also national defence waste other than the nuclear deterrent force (objects containing tritium – night vision systems for example). As at the end of 2013, the share of waste from the small producers represents just over 100 m^3 for an estimated inventory of about 150 TBq.

A significant increase in the inventory of tritiated waste produced in France is expected, owing to the commissioning of the ITER fusion facility. Thus, for all the producers, the inventory of tritiated waste requiring storage before disposal could by 2060 reach a volume of about 30,000 m^3 for a radiological tritium activity of about 35,000 TBq.

These waste are grouped according to their tritium inventory and more specifically their level of gas release:

- very low level tritiated waste (pure or mixed tritiated waste),
- pure tritiated waste releasing little gas,
- pure tritiated waste releasing gas,
- tritiated alpha waste,
- tritiated irradiating waste containing short-lived radionuclides,
- tritiated irradiating waste containing long-lived radionuclides.

Waste containing tritium in significant quantities requires specific management owing to its very mobile nature. Tritium, with a short half-life (12.3 years), is hard to contain and can migrate into the biosphere. The acceptance of tritiated waste in Andra's repository is limited and, for most of the tritiated waste, requires prior treatment or decay storage. The studies aiming to determine a management route for these waste, carried out pursuant to Article 4 of the 28th June 2006

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[203] This indicator is used to monitor progress in terms of characterisation of activated waste from the small producers; characterisation is a pre-requisite for the definition of an appropriate management route.

Programme Act on the sustainable management of radioactive materials and waste and to the PNGMDR, enabled a management route to be defined as follows:

- processing for tritiated waste with an activity level or tritium gas release level that is too high to allow storage in conditions that are safe for individuals and the environment. The Valduc facilities thus enable tritiated waste to be heat treated (by melting for metal waste and baking for organic waste) in order to reduce their activity and/or their tritium gas releases. Following this processing, the tritiated waste is very low level;
- incineration in Centraco for the liquid waste, for example, the scintillating liquids used for analyses (to be accepted in Centraco, tritiated waste must have a tritium activity of less than 20 kBq/g);
- decay storage for tritiated waste which cannot be accepted in Centraco or in the Andra repositories in service or being studied. In addition to the existing tritiated waste storage facilities, in particular in the CEA centres in Valduc and Marcoule, a storage creation programme was defined by CEA, the details of which are presented below;
- disposal for tritiated waste releasing low levels of gas (to be accepted, the tritiated waste must have a tritium gas release value of less than 1 GBq/year/package).

The main tritiated waste storage facilities are located in the CEA centres in Valduc and Marcoule:

- Valduc: at the end of 2012, the storage capacity was increased, with the commissioning of a storage facility for pure tritiated waste releasing gas. At the end of 2013, 14,343 packages were stored, out of a capacity of 21,500 packages, or occupancy of 63%;
- Marcoule: about 200 m^3 of tritiated waste are stored on the Marcoule site. These waste will eventually be removed to the Valduc centre, when new storage capacity is commissioned.

Furthermore, a storage project for tritiated waste on the CEA Cadarache centre, called INTERMED, was the subject of a safety options file submitted to ASN in 2014. It more specifically concerns VLL and LLW/ILW-SL solid tritiated waste produced during the operation of the ITER installation.

Each tritiated waste family is associated with a storage concept for a period of fifty years, to allow decay of the tritium activity in the packages and enable them to be accepted in Andra's repositories[204].

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[204] The storage concepts are presented in detail on p. 115 of the 2013-2015 PNGMDR.

Given the production volumes of its tritiated waste, the forecast schedule for commissioning new storage facilities is the following:

Tritiated waste family	Storage building	Existing storage facilities or anticipated commissioning date	Location
Pure tritiated waste releasing little gas*	Building for Pure tritium releasing little gas Tranche 2	2025	Valduc
	Building for Pure tritium releasing little gas Bis Tranche 1	2037	
	Building for Pure tritium releasing little gas Bis Tranche 2	2041	
Very low level tritiated waste	VLLW Building	2019	Valduc
Pure tritiated waste releasing gas	Building Pure tritium releasing gas	2030	Valduc
Alpha/Tritiated waste releasing gas	Tritiated alpha Building Tritiated alpha	2021	Valduc
Tritiated irradiating waste with short-lived radionuclides	IR SL Building	2025	Valduc
VLL and LLW/ILW-SL tritiated waste from ITER and small producers	VLL and LLW/ILW-SL (INTERMED) Building	2027	Cadarache
ILW-LL tritiated: pure tritiated waste from ITER	Existing building on ITER site preferably	2060	ITER site

Forecast storage creation schedule

* The first tranche was commissioned in 2012.

The waste generated by the ITER installation is present in the installation's preliminary safety analysis report transmitted as part of the BNI creation authorisation application.

ITER-Organization, the nuclear licensee for the ITER installation, is responsible for managing the waste to be produced by this installation. The Agence ITER-France, created within CEA, is responsible for implementing the disposal route, in particular for the tritiated waste to be produced. This service undertaking, made in preparation for the installation in France of the ITER project, is described in the ITER international agreement of 21st November 2006[205]. It will lead to a contract between ITER-Organization and the French stakeholders involved in the route, for management of the operating waste and that produced during the operations prior to decommissioning.

In the light of the tritium content and gas release levels expected in the ITER nuclear waste, most of it will not be directly acceptable in Andra's repositories. Depending on the type of waste, the solution for the time being is as follows:

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[205] The terms of this agreement are available on the website of the ITER organisation: https://www.iter.org/fr/legal/status.

- storage of ILW-LL[206] tritiated and purely tritiated waste in the ITER installation for the duration of the operating phases and the operations in preparation for decommissioning,
- storage of packaged LLW/ILW-SL and VLL waste on the ITER site for 6 months, before direct transfer to Andra's repositories or, in the meantime, to the INTERMED storage facility, to allow decay of the tritium activity in the packages.

Working groups have been set up to optimise management of the ITER waste.

In its opinion of 2nd February 2016[207], ASN stated that it considered that in principle a solution which involved environmental discharge of the tritium contained in the tritiated waste in its various forms is not environmentally acceptable and cannot be a reference management solution, in particular for the "pure tritiated" waste.

R11- By the end of 2017, CEA and Socodei, together with Andra, shall present an analysis of the comparison, for different types of tritiated waste (liquid or gaseous, but also solid, waste contaminated with tritium or "pure tritiated waste, waste from the "small producers"), with regard to the protection of individual health, safety and the environment, of different tritiated waste management solutions, comprising storage, incineration (with or without prior storage) and direct disposal, so that in the 2018-2021 PNGMDR a decision can be reached on whether incineration is the best available technique (BAT) for certain types of tritiated waste. This analysis will more particularly take account of the radioactive and chemical discharges resulting from the incineration process.

Concerning solid tritiated waste from the small producers outside the nuclear power sector, the reference solution adopted in the 2013-2015 PNGMDR is storage shared with ITER waste in the INTERMED facility, for which commissioning is envisaged in 2027. Pending the definition of a management route for gaseous tritiated waste, the reference solution proposed by Andra and being examined by CEA is also storage in this facility.

Pending the commissioning of this storage facility, Andra - together with CEA – has examined the possibility of accepting the tritiated waste from a defaulting responsible party. Such waste could be accepted in the Valduc storage facilities, subject to approval by ASND and provided that:

- the urgent nature of resorting to this solution can be justified,
- the waste comply with the acceptance specifications for the storage facilities concerned,
- limited quantities are involved, not jeopardising the primary purpose of the installations intended for the activities of the deterrent force,
- evacuation routes are identified such that the temporary nature of storage in Valduc is guaranteed.

R12 – The storage of waste in secret BNIs, if this waste does not come from activities related to the deterrent force, can only be accepted if the urgency can be proven and in limited quantities. The storage facilities for such waste should as a priority be covered by the ICPE or BNI system, in particular to ensure compliance with the consultation and information procedures.

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[206] Their packaging is currently being studied.

[207] ASN opinion 2016-AV-0253 of 2nd February 2016 on studies for the management of certain particular waste categories is available on the website: http://www.asn.fr, heading « les actions de l'ASN », « la réglementation », « bulletin officiel de l'ASN », « avis de l'ASN ».

R13 – Andra shall study the possibility of its facilities accepting tritiated waste from defaulting responsible parties, for storage or disposal, by 31st December 2020.

With regard to liquid[208] and gaseous[209] tritiated waste from small producers, the study of the management routes carried out by Andra for the 2013-2015 PNGMDR showed that these waste could be accepted in none of the existing or planned routes. These waste must be treated (primarily by destruction, in particular by means of heat treatment), or made solid to enable them to be accepted in a repository[210].

R14 – The studies carried out on storage of tritiated waste by small producers in the planned INTERMED facility should not compromise the continuation of the programme to search for a final management solution.

R15 – Given the characteristics of the tritiated waste, in particular its mobility in the environment, there should be only a small number of storage facilities.

R16 – Liquid and gaseous tritiated waste from small producers are to be declared in the category of waste without management route in the National Inventory. Andra shall continue with the work to consolidate the inventory of tritiated waste (solid, liquid, gaseous) from small producers and that held by the national defence forces.
Before 31st December 2017, Andra shall send the Minister responsible for energy the strategy envisaged for the management of solid tritiated waste from the small producers, pending the commissioning of storage facilities planned for ITER.

R17 – Andra shall continue to search for appropriate management routes for gaseous and liquid tritiated waste from small producers outside the nuclear power sector and provide a progress report by 31st December 2019. Areva, CEA and Socodei shall take part in this approach to determine the possibility of treating such waste in their facilities and the possibility of acceptance for storage. Sharing treatment facilities for waste from small producers should be an objective.

R18 – The definition of a final management route for all liquid and gaseous tritiated waste from the small producers outside the nuclear power sector should be given by 2025.

I5 – Volume and activity of tritiated waste without a management route

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[208] About 200 litres for an activity of a few TBq.

[209] About 20 m^3 for an activity of a 40 TBq.

[210] The decree of 4th September 1989 authorising the creation of the CSA does not authorise the disposal of liquid or gaseous waste.

4.3.3 Management of used sealed sources

4.3.3.1 Introduction

The term used sealed source refers to any expired sealed source or any sealed source no longer needed by the user, who wishes to dispose of it. A used sealed source is not necessarily waste: a significant share of the sources (more particularly sources of ^{60}Co, ^{137}Cs and ^{241}Am) is recycled by the source manufacturers. They are then considered to be radioactive materials as defined by the Environment Code.

Not all used sealed sources can be recycled or exported to their country of origin, so management solutions must be set up in France for sources for which the decision has been taken to manage them as radioactive waste. This decision is usually the responsibility of the manufacturers, after collection from the users, or of the suppliers.

Creating a management route requires definition of:

- the repository acceptance criteria, for each existing or planned repository,
- the packaging solutions appropriate to the various types of sources and to each repository,
- the needs and solutions for interim storage,
- the organisation of periodic collection campaigns[211] for unused sealed sources from teaching facilities or university laboratories, health institutions and local authorities.

A working group was set up for the 2013-2015 PNGMDR. This "Sources WG" analysed the situation and the needs and drafted recommendations concerning the first three points in its report of 19th December 2014[212].

R19 – In order to evaluate the implementation of the recommendations of this working group, Andra shall:

- **by the end of 2017, present monitoring of the deployment of management solutions for used sealed sources considered as waste;**
- **with the owners concerned, continue to examine the need for the disposal of sources held by the suppliers, in particular in the following cases: sources from the electronics industry, smoke detectors, luminescent sources and objects.**

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[211] Collection campaigns were organised in the past by Andra and by the sources GIP (set up by CEA and CisBio) for the sources manufactured by CEA. The national coordination of PCR networks (CorPAR) could forward the information to those in possession of unused sealed sources.

[212] The report submitted by the used sealed sources working group pursuant to the 2013-2015 PNGMDR is available on the websites of ASN and the Ministry responsible for energy:

- http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015 ;
- http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

4.3.3.2 Recovery of used sealed sources

Article R. 1333-52 of the Public Health Code requires that those in possession of sealed sources have then recovered after a period of ten years, unless a possession extension waiver is granted.
The supplier of sealed radioactive sources is for its part obliged to recover any sealed source it has distributed, unconditionally and whenever requested.
Since 1st July 2015, this article makes provision for recovery by any source supplier (and not simply the original supplier or whoever has acquired it) and, as a last resort, by Andra. This notion of "last resort" more specifically means that the original supplier cannot be identified or that these sources cannot be recycled in the technical and economic conditions prevailing at the time.

R20 – To take account of these new regulatory provisions concerning the recovery of used sealed sources, Andra must:
- **conduct a forecast evaluation of the inventory of sources liable to be collected as a last resort when requested by those in possession of them, pursuant to Article R. 1333-52 of the Public Health Code, for the next 5 years;**
- **ensure that its storage capacity (volume and radiological) is compatible with the estimated inventory.**

4.3.3.3 Repository sealed source acceptance criteria

The specificity of sealed sources is their concentrated activity and their potential attractiveness. This explains their limited acceptability for disposal.

The CSA as of now and the Cires since 2015 have acceptance specifications allowing the disposal of radioactive waste packages containing sealed sources. The source acceptance criteria in the CSA are linked to unspecified human intrusion scenarios on the disposal site (for example, road-building and construction of residential buildings on the repository), at a time by which all recorded traces of the site are assumed to be lost (300 years). These intrusions would make it possible for persons unaware of the potential danger to recover sources.

Several exposure scenarios were considered, in particular:
- placing a source in a pocket,
- keeping a source as an ornament,
- destruction of a source,
- ingestion of a source.

On the basis of these exposure scenarios and the resulting doses, the activity per source was limited (notion of source activity limit (LAS), which depends on the isotopes the source contains). In a study published by Andra in 2008 concerning the sustainable management of used sealed sources, this analysis method is supplemented by taking account of the dimension of the sources.

Disposal in the Cires
The acceptance specifications for this disposal facility were modified in 2015 so that used sealed sources could be accepted while complying with the centre's safety case. The sources initially accepted in the Cires are those with an activity of less than 1 Bq 30 years after acceptance. This will in particular allow the management of totally decayed legacy sources, or very short-lived sources widely used in nuclear medicine, such as Cobalt-57 or Germanium-68. Owing to the very short

half-life of the radionuclides used, these sources cannot be recycled. They will therefore have to be declared by those in possession of them as radioactive waste and are thus eligible for direct collection by Andra.

R21 – While ensuring compliance with protection of individual health, safety and the environment, Andra shall examine the benefits and the possibility of reassessing the 1 Bq criterion, opting for definition of a source activity limit (LAS) per radionuclide, rather than a fixed value, as is planned for the CSA.

Disposal in the CSA

The current CSA sealed source acceptance specifications limit the types of sources acceptable for disposal. The maximum specific activity of the packages is in particular limited to one tenth of the maximum specific activity of the other radioactive waste packages and all mixing of sealed sources and radioactive waste is prohibited.

R22 – While ensuring compliance with protection of individual health, safety and the environment, Andra shall examine the possibility of making the following changes to the Aube repository acceptance specifications:

- **reassessment of the specific activity criterion (LAM) of the waste packages;**
- **taking account of size for large sources, when determining the LAS;**
- **acceptance of multi-radionuclide sources;**
- **acceptance of certain neutron sources;**
- **acceptance of sources containing tritium.**

Generically in the CSA and the Cires,

R23 – While ensuring compliance with protection of individual health, safety and the environment, Andra shall examine the possibility of making the following changes to the Aube repositories acceptance specifications:

- **study the feasibility of the repositories accepting specific sealed sources comprising no physical barrier as ordinary radioactive waste (for example, electro-deposited sources) so that their physico-chemical nature can be taken into account, and considering them more to be unsealed objects without the same potential consequences in the event of intrusion a long time in the future;**
- **define procedures so that, as and when necessary, mixtures of sources and other waste could be accepted in the current disposal routes, while retaining the traceability of the sources, which could in particular make it simpler to create waste packages, given the small volumes concerned (see §4.3.3.4).**

Disposal project for LLW-LL type waste

The design of a repository for low level, long-lived type waste (LLW-LL) has not yet been frozen. The characteristics of the sources acceptable for this type of repository will depend on its final design and in particular its siting depth, along with the envisaged erosion mechanisms.

R24 – In the LLW-LL type waste disposal project currently being designed, Andra shall draw up preliminary acceptance criteria for used sealed sources for submission of the repository's safety options file. These could be based on a safety approach comparable to that of the CSA (LAS).

Deep geological disposal project

In accordance with the provisions of Article L. 542-1-2 of the Environment Code, radioactive waste which, for reasons of nuclear safety or radiation protection, cannot be disposed of in surface or near-surface repositories, must be disposed of in a deep geological layer.

Sources which will not be acceptable in the above-mentioned facilities will thus be disposed of in a deep geological repository, given that the unspecified human intrusion scenarios will not be considered for this repository, owing to the envisaged depth. As necessary, appropriate processing or packaging shall enable the sources concerned to meet the acceptance specifications to be set by Andra for HLW and ILW-LL waste.

R25 – The case of used sealed sources must be included when drafting the preliminary acceptance specifications for the Cigeo project, which will be submitted with the project's safety options.

The definition of disposal acceptance specifications is not sufficient to finalise the implementation of a management route considering used sealed sources to be radioactive waste. The following are also necessary:

- define and deploy packaging solutions accepting the sources or specific to the sources and enabling primary packages to be produced,
- define and deploy disposal solutions (definition of disposal packages and their emplacement),
- create interim storage capacity.

4.3.3.4 Packaging solutions to be created

The "Sources WG" set up for the 2013-2015 PNGMDR focused on drafting a reference strategy for source packaging and on clarifying the disposal routes associated with each packaging solution[213]. For certain source families, prior treatment needs have been identified: this will more particularly be the case of sealed sources containing occluded gases[214].

The reference strategy produced by this group consists first of all in managing the following types of sources in "ordinary" radioactive waste routes, with no specific reference to their status as sealed sources:

- tritium sources (tritiated waste management route): disposal in Andra's facilities or decay storage, depending on the activity level;
- liquid sources (liquid waste management route);
- incinerable sources (Centraco);
- reactor start-up sources (same routes as reactor irradiated internals);
- sources without physical containment barrier, including electro-deposited (all compatible solid waste routes).

The other sources would be managed in routes specific to the source (source packages), without excluding the possibility of some of these source packages eventually being able to accept controlled mixtures of sources and waste.

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[213] The working group drew on previous work by Andra and CEA, a detailed description of which can be found in the 2013-2015 PNGMDR.

[214] Owing to the obligation of disposing of waste in solid form.

Several types of packaging were proposed by the “sources WG”: 1 m^3 container for VLL waste and 5 m^3 for VLL/ILW-SL waste, 870 L “multi-disposal” package acceptable for LLW/ILW-SL, LLW-LL and ILW-LL waste, and welded metal packages for HLW waste.

4.3.3.5 Storage needs and solutions

Interim storage is needed to allow effective management of the sources:

- storage by some users:
    - sealed sources under Ministry of Defence responsibility are stored on various sites, including some on the Saint Priest site, which is shortly to be relinquished. The Ministry is in discussions with Andra concerning the recovery and storage of its radioactive waste as well as the sources with no management solution,
    - EDF’s sources are stored on-site; the volumes concerned are low; however EDF has undertaken a campaign to have its sources recovered by the suppliers or manufacturers concerned;
- temporary storage of sources collected by the suppliers or manufacturers:
    - all the suppliers have a buffer storage capacity, prior to disposal of the sources, usually by return to their own manufacturer,
    - the “sources WG” did not however examine the case of suppliers of certain source categories (electronics industry for arresters and surge protectors, GESI for ion smoke detector sources, suppliers or owners of radio-luminescent objects);
- storage associated with packaging or disposal processes:
    - the HL sources GIP and CEA use or intend to use the following facilities: BNIs 29, 72, 164 and 175 (DIADEM facility currently under construction in Marcoule) and the CERISE ICPE (installation included in BNI 49),
    - Andra uses the Cires facilities for storage of the sources it collects. This same facility is used to group the sources (radium in particular) previously stored on several sites, including those of CEA already mentioned,
    - Andra envisages using the planned INTERMED facility, or another dedicated facility to be created, for decay storage of sources and tritium waste.

4.3.3.6 Consolidated batching of sources to be managed as waste

In order to validate the management strategy proposed, the "sources WG" estimated the quantities of sources to be disposed of for each party in possession, packaging route and disposal solution, for all the routes specific to sources. Two time-frames were taken into consideration:

- for the short to medium term, the accumulated stocks owing to the absence of management routes are considered, along with the foreseeable recovered volume over the coming decade
- for the long-term, an estimation of stabilised traffic, beyond ten years, once the stocks have been dealt with.

These estimates of number of source packages and volume of waste are to be considered an approximation rather than a precise figure.

Forecasts for the first decade (including accumulated stocks):

Disposal route	Type of disposal package	Number of packages (stock)	Number of packages (traffic in 10 years)	Total number of packages	Total volume of packages in repository (m3)
VLLW	Basket 1 m3	6	17	23	23
LLW/ILW – SL	Package 5 m3	31	21	53	265
ILW-LL (CIGEO) or LLW-LL	Package 870 l	78	61	139	121
	CSM packages stored by CEA	41	0	41	123
HLW-LL	CDT 175 l	6	1	7	1,2

Annual stabilised traffic forecasts for a ten-year time-frame and beyond:

Disposal route	Type of disposal package	Number of packages (traffic per year)	Volume of dispoal packages per year (m3)
VLLW (Cires)	Basket 1 m3	1 to 2	1 to 2
LLW/ILW – SL (CSA), ILW-LL (CIGEO) or LLW-LL	Package 870 l	5 to 7	4 to 6

The low traffic levels envisaged for this time-frame show the benefits (at least on this time-scale) of managing sources and waste in the same packages, in order to guarantee the economic viability of the packaging routes and the acceptability for the users of the cost of source recovery, despite the low source traffic anticipated in each route.

4.3.4 Management of waste from small producers outside the nuclear power sector

Since 1979, Andra has been responsible for managing waste from small producers outside the nuclear power sector. This description refers to waste resulting from activities outside the nuclear power sector which handle radioactive substances and consequently produce radioactive waste. These activities are mainly involved in research (excluding CEA activities), industrial unrelated to nuclear power and the medical sector. About 1,300 waste owners of this type have been identified. Andra generally collects unpackaged waste and performs sorting, packaging, storage and disposal operations, or has them carried out on its behalf. According to the collection guide published by Andra[215], 80 tons of waste, or about 300 m^3 and 3,000 waste packages are dealt with by Andra.

When it was created in 1991, Andra did not have its own facilities for managing waste from small producers outside the nuclear power sector. Consequently, these services were mainly provided by Andra's contractors. Andra started reconfiguring the route in 2012 by creating Cires, a collection centre and a storage facility for waste from small producers outside the nuclear power sector. In addition, Andra plans to commission a sorting and processing unit in 2016.

Andra has also initiated an update of the management procedures for these waste, to tailor the process more closely to the nature, activity and volume of waste. This update also aims to minimise the cost of processing. It was applied to very low level waste which could be disposed of directly, which was redirected from the low level waste management routes (incineration, disposal) to Cires.

Apart from the permanent goal of reducing acceptance times, Andra thus aims to secure and diversify the routes in order to reduce dependence on a single facility and the corresponding potential risks, based on the lessons learned from the Centraco accident in 2011.

4.3.5 Management of Malvési waste

The Areva NC industrial site in Malvési (Narbonne) has since 1960 been carrying out the first step in the conversion necessary for the nuclear fuel cycle. It is the single point of entry into France of the natural uranium from the mines and it carries out purification and conversion of this uranium into uranium tetrafluoride (UF_4).

The liquid effluents from the process are neutralised with lime and then sent to settling ponds, where solid-liquid separation takes place. The settling ponds thus gradually fill up with the solid fraction of the effluents (fluorine and metallic hydroxide sludges) constituting the solid waste from the conversion process. The liquid fraction of the effluents, clarified by settling, is sent to the evaporation ponds where it is concentrated by natural evaporation.

The settling ponds used by the Malvési industrial installations are located on a base consisting primarily of waste rock and mining residues from a former sulphur mine, which closed in 1953. It should be noted that from 1960 to 1983, the installation also converted the uranium from processing of spent fuels (URT) into UF_4, hence the presence of traces of artificial radionuclides in the solid waste stored in the former B1/B2 settling ponds. Owing to the presence of these artificial radionuclides, these ponds – which are within the perimeter for the ECRIN facility – are subject to the BNI system.

The specificity of these waste (large volumes, presence of natural radionuclides from the uranium and thorium chains) explain that they are not a part of the existing or planned disposals routes and are recorded in the National Inventory[216] in the RTCU family of "uranium conversion processing residues".

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[215] Andra's June 2014 radioactive waste collection guide is available on the Andra website: www.andra.fr, heading « guide ».

[216] National Inventory of radioactive materials and waste (ANDRA document – 2015 edition), available on the Andra website: www.andra.fr.

As at the end of 2013, this inventory showed about 300,000 m^3 of waste produced since 1960 and stored in the ECRIN BNI. This volume includes process sludges, earths and materials recovered since the collapse of the embankment in 2004, as well as the quarry materials used as the cover.

As at the end of 2013, the RTCU inventory also took account of:

- 354,000 m^3 of nitrated liquid effluents present in the evaporation ponds,
- 50,000 m^3 of sludges contained in settling ponds B5 and B6.

The fraction of waste rock and mining residues present under the former B1 and B2 ponds, which could be potentially affected by their past operation, must be added to this inventory. The 2013-2015 PNGMDR prescribed investigations concerning the mining waste rock situated under ponds B3, B5 and B6. These investigations will be performed when these ponds are drained for storage of the sludges they contain in the former ponds B1 and B2. This drainage is subject to ASN authorisation for commissioning of the ECRIN facility and could take place as of 2017.

In accordance with the recommendation in the 2013-2015 PNGMDR to differentiate between management of the waste produced since 1960 and management of the waste to be produced by the end of the lifetime of the industrial installations, the Areva NC Malvési site carried out an overall review of the short, medium and long-term management of the conversion process waste.

With regard to "legacy" waste, in part already stored on the site, the selection of the most appropriate management scenario comprises two aspects:

- safe short and medium-term storage of the waste, maintaining it in a reversible condition with a view to final management,
- the search for a long-term management solution close to the site, organised around an ongoing study and research programme.

Short and medium term:

The initial work to make the settling ponds safe for their short-term management started in 2006, with reinforcement of the geotechnical stability of all the mining waste rock embankments. It was followed in 2012-2013 by environmental consolidation work, consisting of an underground wall associated with a peripheral drainage network, to control underground circulation and protect the alluvial water table. In conjunction with the increased capacity of the water treatment installations, all rainwater and groundwater in this sector is today collected and treated on the Malvési site. The commissioning license for the ECRIN facility should allow the creation of a cell to store the desiccated sludges from the drainage of the B5 and B6 settling ponds and the installation of a bituminous cover over a surface of about 6 hectares covering the legacy process waste store.

This cover, together with the environmental consolidation system should be able to prevent the risks of dissemination of radioactive and chemical substances through the water.

Long-term:

In accordance with the 2013-2015 PNGMDR, Areva NC submitted a report at the end of 2014 on the progress of the feasibility studies for the three disposal options which had been proposed at the end of 2011 concerning the search for a safe long-term management solution for the waste stored on the Malvési site.

The studies presented in the progress report are still lacking in detail but do present data considered by Areva NC to be favourable at this stage and which do not compromise the continuation of the studies (in particular the existence right next to the site of two geological media of sufficient thickness and with mineralogical and geochemical characteristics relatively favourable to limiting the dissemination of chemical and radioactive substances). It should be noted that the results acquired are supplemented by periodic progress reports from Areva NC in accordance with the creation authorisation decree for the ECRIN facility[217]. These studies concern the geological and hydrogeological survey as well as the processing and packaging of waste and the design of the disposal facility.

R26 – Areva NC will be looking for and implementing a final management solution for the waste stored on the ECRIN BNI. Areva NC will thus submit a progress report on this search before 31st July 2020.

With regard to the waste to be produced as of 1st January 2019, to ensure the long-term operation of the site and secure the management of the future process solid waste, Areva NC is currently working on two projects aiming on the one hand to reduce the volume of solid waste produced and give preference to existing management routes and, on the other, to use (thermal) processing of the future process liquid effluents, jointly with those already stored in the evaporation ponds.

These future process changes would lead to differentiation between four potential families of process waste to be produced:

- fluorines and gypsums from a change in the process, consisting in separation at source of the waste to be produced by the plant in the future,
- a stock of desiccated sludges from the drainage and filtration of the waste already present in the settling ponds when the change is made to the previous process,
- solid waste from thermal processing of the nitrated liquid effluents which will be produced by future operation of the conversion facilities, but also by recovery of the stock already stored in the evaporation ponds.

In accordance with the request in the 2013-2015 PNGMDR, Areva entrusted Andra with examination of the long-term management routes for these waste to be produced and in particular a study of their acceptability in a VLL waste route and the compatibility of any non-VLL waste with near-surface disposal.

Concerning the solid waste from processing of the nitrated effluents and fluorines, Andra confirms that they are liable to fall into the VLL category but specifies that the volumes are significant and are not at present included in the Cires inventory. In its opinion of 2nd February 2016[218], ASN recommends that these waste be taken into account in the VLL waste inventory. With regard to

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[217] Decree of 20th July 2015 authorising AREVA NC to create and operate a BNI called ECRIN (confined storage of conversion residues) on the Malvési site in the municipality of Narbonne (Aude *département*).

[218] ASN opinion 2016-AV-0253 of 2nd February 2016 on studies for the management of certain particular waste categories is available on the website: http://www.asn.fr, heading « les actions de l'ASN », « la réglementation », « bulletin officiel de l'ASN », « avis de l'ASN ».

desiccated sludges and gypsums, Andra states that in the light of their radiological characteristics, they not be classified as VLL, but be sent to another management route, yet to be defined. The preliminary forecast analysis of the conditions for the acceptability of these waste in a near-surface repository was thus carried out, clarifying the issues involved in the management of these waste and helping to determine the focus of the subsequent studies: reduction of nitrates concentration for the sludges and availability of a specific disposal design for gypsums which, in a reduced volume, concentrate the activity of the long-lived natural radionuclides present in the mining concentrates.

To conclude, in the light of the exploratory analysis carried out jointly by Areva and Andra, more than 90% of the annual traffic of waste to be produced would meet the Cires acceptability criteria. The rest (stock of desiccated sludges and annual gypsum traffic) is subject to an appropriate management route yet to be defined. Andra however stresses the exploratory nature of the exercise, but does point out that the compatibility with the LLW-LL disposal project being studied by Andra has not yet been examined.

Depending on the results of the coming studies and assuming that these waste are not compatible with the near-surface disposal project being studied by Andra, Areva considers that the following avenues are to be envisaged: continue R&D to optimise the overall acceptability of these waste and further reduce their volume (possibly with reutilisation in mining installations of the uranium contained in these gypsums) and, failing which, manage these waste with Malvési legacy waste.

The guidelines concerning the management of the waste produced by the Areva NC plant in Malvési requiring a LLW-LL management route are defined in chapter 4.1.

R27 – The VLL waste produced as of 1st January 2019 by the Areva NC plant in Malvési requires a VLL route and is included in the forecast inventory of VLL waste.

R28 – The LLW-LL waste produced as of 1st January 2019 by the Areva NC plant in Malvési requires a LLW-LL route and is included in the forecast inventory of LLW-LL waste.

R29 – Before 31st December 2017, Areva shall draft a management strategy for the desiccated sludges currently produced by the Malvési plant and which will not be stored in BNI 175 called Ecrin. If desiccated sludges were to be produced after 2019, they will be included in the forecast inventory of LLW-LL waste.

4.3.6 Management of waste resulting from a nuclear accident – The Steering Committee for managing the post-accident phase

The interministerial directive of 7th April 2005 on the action of the public authorities in the case of an event leading to a radiological emergency situation tasked ASN, together with the ministerial departments concerned, with establishing the framework and defining, preparing and implementing the necessary measures for responding to post-accident situations. In June 2005, ASN set up a Steering Committee to manage the post-accident phase following a nuclear accident or radiological emergency situation (CODIRPA), responsible for developing the corresponding doctrine and it in particular set up 11 working groups (WG).

Contents

To support the working groups until November 2012, the CODIRPA adopted two intermediate severity accident scenarios for an NPP: a scenario with partial reactor core melt and a steam generator tube rupture. The eleven working groups met: each group drafted a final report summarising its conclusions on the assigned topic. In 2010, local experiments were carried out on three NPPs and in several surrounding communes, to test the doctrine currently being constructed.

The purpose of the CODIRPA was to prepare provisions designed to address complex post-accident management problems, in particular those concerning the health management of the populations, the economic consequences, or the rehabilitation of living conditions in the contaminated zones. In the light of these issues, three fundamental objectives were identified for post-accident management of a nuclear accident:

- protect the populations against the dangers of ionising radiation;
- provide support to the population that suffers the consequences of the accident;
- reclaim the territories affected, in economic and social terms.

The approach followed by the CODIRPA led to the drafting of aspects of a post-nuclear accident management doctrine, published on 21st November 2012[219]. This doctrine is based on the international principles of radiation protection, but also on guideline values taken from the work of the CODIRPA. It comprises management objectives and various means of achieving them, in order to deal with a situation that is by its nature complex, owing to the large number of subjects to be dealt with and the number of players involved.

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[219] Aspects of doctrine are available on the ASN website http://www.asn.fr, heading « les dossiers », « la gestion post-accidentelle », « comité directeur de phase post-accidentelle ».

Waste management in the post-accident phase

For implementation of contaminated territories reclamation and population protection strategies, waste management in the post-accident phase must follow an overall goal of reducing ambient radiological contamination, by limiting the impact of this management on the public and the response teams, more specifically by limiting the transport of contamination outside the zones contaminated by the accident and therefore, whenever possible, opting for management of this waste within these zones. In a normal situation, the principles of radioactive waste management are defined in the Environment Code and in the PNGMDR. In a post-accident phase, the nature and volume of the waste to be managed, the availability of the waste management facilities and the potential radiological impact of the processing or removal of certain contaminated waste are all criteria which must underpin the choice of contamination reduction measures, the choice of population and environmental protection measures and the choice of waste management solutions, with the aim of optimising waste management.

The first step in post-accident management of waste is to differentiate between the contaminated waste and the non-contaminated waste. It would appear to be relatively unrealistic to expect waste management to be organised on the basis of measuring the radiological activity of the waste, in particular because the measurement resources available on exiting the emergency phase will probably be used to characterise the environment or to monitor the radiological activity of foodstuffs. **It is therefore proposed that the waste be managed according to its origin (zones of various degrees of contamination).** These zones would initially be identified on the basis of the results of predictive assessments. **These zones would be based on those defined for protection of the populations and for reinforced monitoring of areas determined according to the objectives of management of post-accident consequences:**

The Population Protection Zone (ZPP) corresponds to the perimeter within which measures to reduce the exposure of the people residing there are justified. This zone is defined according to a radiation protection objective for the population living in the most heavily contaminated areas;

The Heightened territorial Surveillance Zone (ZST) extends beyond the Population Protection Zone. It is characterised by lower environmental contamination which does not in principle warrant population protection measures, other than a ban on marketing of foodstuffs produced locally and recommendations designed to limit the consumption of certain foods produced locally or derived from hunting, fishing or gathering.

The waste considered as contaminated is waste produced in the ZPP as a result of the accident, barring special cases. This waste will be specially stored in a facility to be gradually brought on-line. However, exceptional provisions may be authorised as of the exit from the emergency phase, when perishable waste cannot be stored (for example: spreading of milk), although account must be taken of the vulnerability of the soil and the water resources.

In and beyond the ZST, all waste would be considered to be non-contaminated. It can be processed or disposed of in accordance with the usual practices, subject to certain provisions, for example in facilities equipped with radioactivity detection gantries. In-situ periodic measurement of the radiological activity of certain waste could however be envisaged, in particular for the sludges produced in water treatment plants, in which the radioactivity is liable to become concentrated.

Follow-up of the work already done

The accident which occurred in March 2011 in the Fukushima Daiichi NPP in Japan recalled the importance of an approach such as that adopted by the CODIRPA, but also identified new challenges for the management of such an event. The approach was thus continued, on the one hand to ensure that national doctrine is implemented in the regions and, on the other, to envisage a long-duration and large scale accident scenario, which had not been studied hitherto.

It should be noted that in the event of a long-duration, large-scale accident, the areas liable to be included in the post-accident zones (ZPP and ZST) would be far larger than in the case of a medium-scale accident and short-duration releases. The ZPP would typically cover several tens of km² and the ZST several hundred km². However, as shown by the forecast evaluations already made, the distances over which the MPL[220] are exceeded and determining the scale of the ZST would decrease relatively rapidly during the first few weeks of the post-accident phase, in particular owing to the decay of radioactive iodines.

In order to develop CODIRPA doctrine on the management of radioactive waste, a dedicated working group was set up at the end of 2015, with ties to the PNGMDR working group. Its work will first of all focus on the following points:

- an analysis of the lessons learned from Fukushima and in particular the good and bad practices in the field;
- a comparison between the lessons learned from Fukushima and current CODIRPA doctrine as formulated in the 21st November 2012 report;
- as applicable, proposals to modify this doctrine.

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[220] Maximum Permissible Levels: these are levels defined by the EURATOM regulations, setting values not to be exceeded for the foodstuffs most vulnerable to radioactive contamination

Conclusion

Radioactive materials and waste must be managed sustainably, to protect individual health, safety and the environment, in accordance with the provisions of the Environment Code. For this purpose, the definitive safeguarding of radioactive waste must be sought and implemented in order to prevent or minimise the burdens to be borne by future generations.

There is a wide variety of radioactive waste, according to the activity and half-life of their radionuclides and according to the chemical substances they contain. Each type of waste, from production to disposal, must thus undergo management appropriate to its type, in order to control the risks inherent in it, more specifically the radiological risks. Management of radioactive waste is the responsibility of the producers and the French national radioactive waste management agency (Andra), under the control of the French nuclear safety authority (ASN) and the defence nuclear safety authority (ASND). It is carried out in compliance with the objectives set out in the PNGMDR.

Long-term management solutions for radioactive waste have been determined for VLLW and LLW/ILW-SL waste, which represent the vast majority of the volume of radioactive waste. The search for long-term management solutions for LLW-LL and HLW/ILW-LL waste must however be continued and, in the meantime, storage-based management solutions will be used.

The work done in the successive editions of the PNGMDR aim to continually improve and optimise the existing management methods and make progress in implementing new routes for all waste. It goals are to reduce the quantity and harmfulness of the waste and to create the disposal facilities defined by the Environment Code.

The 2016-2018 edition of the PNGMDR draws on the results of the work done by the previous plans as well as on the information in the National Inventory of radioactive materials and waste published in 2015 by Andra. It follows on from the previous version, reinforcing the management route based approach, more particular by creating or updating the corresponding overall industrial systems. It also requests the identification of new capacity and management equipment, in particular for storage, necessary for the correct working of the solutions, so that the implementation deadlines can be determined. It stresses the need for consolidation of radioactive waste production forecasts, VLL waste in particular, and greater substantiation of the possible reuses of certain radioactive materials.

This fourth edition of the PNGMDR also underwent an environmental assessment and a public consultation such as to reinforce the consideration given to environmental aspects, while recalling the beneficial purpose of the plan itself. It also presents indicators for assessing the progress made in implementing the plan, pursuant to Council Directive 2011/70/Euratom, establishing a community framework for the responsible and safe management of spent fuel and radioactive waste, adopted on 19th July 2011.

The 2016-2018 PNGMDR, plus its environmental report, was transmitted to Parliament in early 2017 and will be evaluated by the OPECST. In accordance with the provisions of Article L.542-1-2 of the Environment Code, a new decree stipulating the provisions of the 2016-2018 PNGMDR will be published to give official shape to the requirements and the studies to be conducted. This

Plan, its summary, its environmental assessment and the various corresponding documents will also be available for consultation on-line on the ASN and DGEC websites.

Glossary

4N (chain): Number of nucleons in an atom
ACRO: Association for the Control of Radioactivity in the West
ADS: Accelerator Driven System
AFSSA: French Agency for Food Safety
ANCCLI: National Association of Local Information Committees and Commissions
Andra: French national radioactive waste management agency
ASN: French nuclear safety regulator
ASND: Defence nuclear safety authority
BNI: Basic Nuclear Installation
Bq: Becquerel
BRGM: Geological and Mining Research Office
CANDU: CANada Deuterium Uranium
CERCA: Compagnie pour l'Etude et la Réalisation de Combustibles Atomiques
Cigeo: Industrial centre for geological disposal
Cires: Industrial centre for collection, storage and disposal
CLI: Local Information Committees and Commissions
CLIS: Local Information and Monitoring Committee
CNAR: National Funding Commission for Radioactive Matters
CNDP: French National Public Debates Commission
CNE2: National Review Board
CNEF: National Assessment Commission for Financing the Cost of Decommissioning Basic Nuclear Installations and Managing Spent Fuels and Radioactive Waste
CNRS: French National Centre for Scientific Research
CODERST: Departmental Council for the Environment and for Health and Technological Risks
CODIRPA: Steering committee for managing the post-accident phase of a nuclear accident or radiological emergency situation
COSRAC: Committee for the Monitoring of Research on the Cycle Back-End
CPDP: French Special Public Debates Commission
CSA: Aube waste disposal facility
CSM: Manche waste disposal facility
CU: Spent fuel
DAC: Creation authorisation decree
DGEC: General directorate for energy and climate
DGPR: General Directorate for Risk Prevention
DGRI: General Directorate for Research and Innovation
DGS: General Directorate for Health
DLI: Incinerable liquid waste
DREAL: Regional Directorate for the Environment, Planning and Housing
DRIEE: Regional and Interdepartmental Directorate for the Environment and Energy
DSI: Incinerable solid waste
ENSREG: European Nuclear Safety Regulators Group
FI: Low level
FNE: France Nature Environnement
FNR: Fast Neutron Reactor

GB1: George Besse 1
GCR: Gas-cooled reactor
GEP: Pluralistic experts group
GESI: French group of Electronic Fire Safety industries
GIP Sources HA: Public interest grouping for high-level sealed radioactive sources
GIP: Public interest grouping
GSIEN: Group of scientists for information on nuclear energy
HCTISN: High Committee for Transparency and Information on Nuclear Security
HL: High level
ICPE: Installation classified on environmental protection grounds
ICRP: International Commission on Radiological Protection
ILL: Laue–Langevin Institute
ILW-LL: Intermediate Level Waste, Long-lived
SBNI: Secret Basic Nuclear Installation.
INERIS: French National Institute for the Study of Industrial Environments and Risks
INSERM: French National Health and Medical Research Institute
IRSN: French Institute for Radiation Protection and Nuclear Safety
LAS: Source Activity Limit
LLW/ILW-SL Low Level and Intermediate Level - Short-lived waste
LLW-LL: Low Level Waste, Long-lived
MEEM: Ministry for the Environment, Energy and the Sea
MESR: Ministry for Higher Education and Research
MI: Intermediate level
MIMAUSA: History and impact of uranium mines: Summary and Archives
MOX: Plutonium and uranium oxides based fuel
MSNR: Nuclear Safety and Radiation Protection Mission
NEA: Nuclear Energy Agency
NEEDS: Nuclear, Energy, Environment, Waste, Society
NORM: Waste with high levels of natural radioactivity (naturally occurring radioactive material)
NPP: Nuclear Power Plant
OECD: Organisation for Economic Cooperation and Development
OPE: Long-term Environment Observatory
OPECST: Parliamentary Office for the Evaluation of Scientific and Technical Choices
PCR: Person Competent in Radiation protection
PDE: Operations Master Plan
PIGD: Industrial waste management programme
PNGMDR: National Plan for Radioactive Materials and Waste Management
PRI: Integrated Radiological Shielding
PWR: Pressurised Water Reactor
R&D: Research and Development
RCD: Retrieval and packaging of waste
RFS: Basic safety rule
RHF: High-flux reactor
SAL: Specific Activity Limit
SCI: Intact cover disposal
SCR: Reworked cover disposal
SG: Steam Generator
SHS: Human and Social Sciences

Sv: Sievert
TENORM (waste): Technologically enhanced naturally occurring radioactive materials (TENORM)
tHM: ton equivalent heavy metal
tHMi: ton equivalent heavy metal irradiated
Uapp: Depleted uranium
UOx: Uranium oxide based fuel
URE: Enriched reprocessed (or recycled) uranium
URT: Reprocessed uranium (or recycled uranium from processed spent fuel)
VLL: Very low level
VSL: Very short-lived
WG: Working group
WHO: World Health Organisation
WISE-Paris: World Information Service on Energy
ZIRA: Zone of interest for in-depth studies
ZPP: Population protection zone
ZST: Heightened territorial surveillance zone

Appendices

Summary of the appendices

Appendix 1: Reminder of the main orientations of the successive PNGMDRs since 2007 and list of studies requested by the 2016-2018 PNGMDR

The 28th June 2006 Programme Act on the sustainable management of radioactive materials and waste confirmed the important role played by a national plan for radioactive materials and waste management and makes provision for its adoption by the Government every 3 years.

The 2016-2018 PNGMDR is the 4th edition of the plan, since the first one covering the period 2007-2009. This edition follows on from the previous plans, with the aim of constantly improving the management of radioactive materials and waste, in compliance with the principles and guidelines initially defined by the 28th June 2006 Act and incorporated into the Environment Code[221].

The main guidelines of the previous PNGMDR and the results obtained are summarised below.

Quality of the inventory of radioactive materials and waste

Improving the quality of the inventory of radioactive materials and waste is a constant concern of the PNGMDR.

Steps to survey legacy disposal sites for nuclear facilities and uranium mining waste rock were for example initiated in the 2010-2012 edition of the PNGMDR and continued in 2013-2015. The new edition asks for the investigations on the legacy disposal sites to be completed by the end of 2017. It also asks that the arguments used by the licensee to make a case by case decision in favour of continued in-situ management of a legacy disposal site shall be sufficiently substantiated to enable the reasons for this choice to be assessed in the light of the safety issues and the protection of the interests mentioned more specifically in Article L. 593-1 of the Environment Code.

With respect to the previous editions, the 2016-2018 PNGMDR reinforces its steps to improve the quality of the inventory forecasts, by asking that the waste linked to soil remediation be identified in the National Inventory of radioactive materials and waste as of its 2021 edition and that the long-term scenarios linked to energy policy hypotheses be increasingly diversified and detailed. The survey of future storage requirements was developed more extensively and the deadlines for the creation of new storage capacity have been defined.

Management of radioactive materials

The actual possibilities for reutilisation of radioactive materials are monitored in each edition of the PNGMDR, which asks that the owners of radioactive materials stipulate the reutilisation processes they envisage or, if they have already provided these data, whether any changes are envisaged.

With the successive version of the plan, this monitoring has led to the definition of criteria to assess whether the radioactive materials are actually reusable. On the basis of the criteria defined in this way, additional substantiation of the actually reusable nature of certain radioactive materials is requested in the 2016-2018 PNGMDR.

In parallel with this monitoring, as of the 2007-2009 edition of the PNGMDR, the owners of radioactive materials were required – as an interim measure – to study the possible routes for their

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[221] Legislative part Book V, Title IV, Chapter 2

management in the eventuality of these materials one day being reclassified as waste. The 2010-2012 and 2013-2015 PNGMDR requested that these studies be carried out in greater detail for thorium. This request for a more detailed study is extended to include depleted uranium and reprocessed uranium from spent fuels in the 2016-2018 PNGMDR.

For each of the above-mentioned substances, the feasibility study for a disposal concept, indicating the associated cost on the basis of their detailed radiological and chemical inventory is expected for the end of 2019. The presentation of the potential impact of the quantities of potentially reclassified materials on the planned disposal routes is expected within this same time-frame.

Management of mining residues

In accordance with one of the objectives of the 28th June 2006 Act, a first review of the long-term impact of the uranium mining residues disposal sites and the implementation of a reinforced radiological monitoring plan for these sites was carried out within the framework of the 2007-2009 PNGMDR. The studies continued and progress reports were provided on the occasion of each PNGMDR update, taking account of the particular requests of these plans.

The work started needs to be continued under the next two PNGMDR in order to complete the studies into the long-term evolution of the mining waste rock processing residues, complete the methodology for assessing the long-term strength of the embankments, study the possibilities for modifying or shutting down the water treatment plants and, finally, to propose concrete measures to reduce the risks and impacts on the various sites.

VLL waste management

In order to anticipate the significant increase in the volumes of VLL waste linked to the forthcoming decommissioning of nuclear facilities, studies on the benefits and technico-economic feasibility of optimising the use of the capacity in the VLL waste repository, either by densification of metal waste and crushed materials, or by reutilising them in the nuclear sector, were initiated by the 2010-2012 PNGMDR.

This approach was continued in the 2013-2015 PNGMDR which explained the conditions for the reutilisation of VLL materials. An overall industrial system for the VLL waste management sector presenting a number of potential complementary avenues for optimisation was presented in this edition.

The 2016-2018 PNGMDR asks that some of the avenues studied (reutilisation of crushed materials in a repository, extension of disposal capacity) be implemented, unless totally unacceptable, and that investigations be taken further more particularly into the reutilisation of metal materials, disposal densification and the creation of other disposal facilities.

A general interim review of then sector is expected for the end of 2020 with an update of the overall industrial system for VLL waste management.

Management of LLW-LL waste

In accordance with one of the objectives of the 28th June 2006 Act, which requires the development of disposal solutions for graphite waste and radium-bearing waste, and once feasibility studies have been completed on such a disposal concept, the 2007-2009 PNGMDR asked Andra to analyse the conformity of the candidate sites with the geological and environmental selection criteria.

In 2009, the representatives of the two potential sites for the geological reconnaissance withdrew. The 2010-2012 PNGMDR thus asked Andra to once again study the various management options for LLW-LL waste. At the end of 2012, the agency sent the Government a report proposing different management scenarios for LLW-LL waste and resumption of the siting process in 2013 at the earliest. A file concerning the feasibility of a disposal facility on a site in the Soulaines region was submitted at the end of 2015 within the framework of the 2013-2015 PNGMDR.

In the light of the remaining uncertainties as to the ability of this site to accept all the waste specified in the reference inventory for the LLW-LL repository, the 2016-2018 PNGMDR more particularly asks that the geological investigations be continued on the site being studied, along with an assessment of the inventory of LLW-LL waste liable to be emplaced in it and the mid-2019 submission of a report presenting the technical safety options for this disposal facility.

An overall industrial system for management of all the LLW-LL radioactive waste shall also be submitted before the end of 2019.

Management of HLW and ILW-LL waste

Following on from the 30th December 1991 Act, the 28th June 206 Act asked that research and studies be continued on high or intermediate level, long-lived radioactive waste, in three complementary areas:

- the partitioning and transmutation of long-lived radioactive elements, in particular to assess the industrial prospects for use in new generation reactors;
- reversible deep geological disposal, in order to select a site and design a repository, which would need to be commissioned in 2025;
- storage, so that dedicated facilities meeting the needs identified by the plan, in particular in terms of capacity and duration, are created no later than 2015.

The studies requested by the successive PNGMDR aimed to coordinate the implementation of the above-mentioned avenues of research. With regard to disposal, this work led to:

- the selection and qualification of a restricted zone for siting of the repository and the submission of a technical file presenting the repository design and safety options in 2009;
- the holding of a public debate on “the project for a reversible deep geological repository for radioactive waste in Meuse/Haute-Marne” in 2013;
- incorporation of points raised during the public debate in 2013, more particularly including the submission of a safety options file in 2016 and the integration of a pilot industrial phase prior to start-up of the installation.
- the definition of the notion of reversibility by Parliament in 2016.

Since the 2013-2015 edition, the PNGMDR has reinforced its requests for studies to ensure that the various HLW and ILW-LL waste management options taking place upstream of disposal work together satisfactorily: packaging, storage, transport. This approach is continued in the 2016-2018 PNGMDR, which more specifically asks that the survey of storage capacity needs be completed, with the adoption of significant time margins and taking account of the scheduling of the shipments to the planned repository.

Waste requiring specific work

The work initiated since the 2007-2009 PNGMDR on waste requiring specific work enabled the following to be carried out:

- in 2008, definition and harmonisation of the regulatory framework applicable to the management of radioactive waste and effluents from the "small producers";
- in 2009, definition of guidelines for the storage of tritiated waste, associating each family of tritiated waste with a storage concept of sufficiently long duration to allow decay of the package activity and acceptance in a disposal route;
- improved survey of used sealed sources and definition of an overall system for their management;
- progress in defining treatment solutions for the acceptance of asbestos, mercury and organic liquid waste without a disposal route.

The guidelines of the 2016-2018 PNGMDR follow on from those of the previous plans and aim to improve solutions for the long-term management of waste requiring specific work. An objective is set for 2030, for the definition of a final management route for all the waste without a disposal route produced before the end of 2015.

Public information procedures

Improving public information is an objective of each successive edition of the PNGMDR. In addition to the publication of a summary of the plan since the 2010-2012 edition and the editorial efforts made to make the plan more accessible, all the work involved in the PNGMDR and followed up by a pluralistic working group is made public (studies and research carried out, opinions on the studies, minutes of meetings, presentations, etc.).

For the first time and in accordance with the provisions of Articles L. 122-4 and following of the Environment Code, the 2016-2018 PNGMDR is also supplemented by an environmental assessment with the aim of improving the way the plan addresses environmental topics.

Studies requested by the 2016-2018 PNGMDR

	Written by	Date of submission
The principles to be considered when defining a radioactive waste management route		
Report on the possible methodology and criteria for assessing the harmfulness of radioactive materials and waste.	IRSN	31st December 2017
The cost of management of radioactive materials and waste		
Detailed data on the cost of managing spent fuels and waste held or managed	Areva, CEA, EDF, Andra	31st December 2017
Management of radioactive materials		
Application for extension of depleted uranium storage capacity to the relevant administrative authority.	Areva	31st December 2017[222]
Feasibility of a depleted uranium disposal concept, corresponding cost, on the basis of a detailed radiological and chemical inventory of these substances transmitted by those in possession of them.	Andra	31st December 2019
Application for creation or extension of URT storage capacity to the relevant administrative authority.	Areva	31st December 2017
Strategy for a medium-term reduction in growth of URT stocks held and then ensure that these stocks are capped.	Areva, EDF	31st December 2017
Feasibility of a reprocessed uranium disposal concept, stating the corresponding cost, on the basis of a detailed radiological and chemical inventory of these substances transmitted by those in possession of them.	Andra	31st December 2019
Comparative study of the environmental impacts of a strategy with processing of spent fuels and one without.	Areva, together with EDF, CEA and Andra	30th June 2018
Strategy for managing PWR spent fuels storage capacity (UOx, URE and MOx spent fuels) and the corresponding calendar for the creation of new storage capacity	EDF	31st March 2017

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[222] If, by the 31st December 2017 deadline, the envisaged date of saturation of current storage capacity is pushed back, the date for submission of the application may be postponed accordingly.

Technical and safety options for the creation of new storage capacity (extension of an existing facility or creation of a new spent fuel storage facility).	EDF	30th June 2017
Submission of an application for authorisation to create a new spent fuels storage facility.	EDF	31st December 2020
Large-scale technical feasibility of processing of spent URE and MOx fuels, quantities of Pu necessary for deploying a fleet of FNR.	Owners (including EDF)	31st December 2017
Types of all the spent fuels being held, the developments required to enable them to be reused and the benefits of the properties of the separated materials with a view to reutilisation. Cost of processing by comparison with direct disposal.	Owners (including CEA)	31st December 2017
Additional substantiation of the effectively reusable nature of all physical-chemical and isotopic forms of the plutonium held.	CEA	31st December 2017
Management of legacy situations		
Investigation of legacy disposal sites, with physical and radiological inventories and management modes adopted.	Areva, CEA, EDF	31st December 2017
Management of mining processing residues and mining waste rock		
Interim review of the management strategy for the waters from former mining sites.	Areva	31st December 2017[223]
Study of the releases from the Bois-Noir-Limouzat site.	Areva	31st March 2017
Supplementary Bois-Noir-Limouzat study with modelling of sedimentation and transfers of radionuclides	Areva	31st December 2018
Waste rock piles survey.	Areva	31st December 2017
Study on the long-term evolution of mining waste rock.	Areva	31st June 2018
Adjustment of mining waste rock evolution model for all the waste rock piles.	Areva	31st December 2019
Modelling of transfer of uranium and radium in the residues disposal sites.	Areva	31st December 2017
Adjustment of evolution model for uranium-bearing mining residues disposal sites.	Areva	31st December 2019

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[223] The complete report is required for the time-frame of the 2019-2021 PNGMDR.

Conclusions in terms of robustness of the embankments around the uranium ore processing residues disposal sites for the target lifetimes and proposals in terms of monitoring and upkeep of the structures, or reinforcement.	Areva	31st December 2018
Results of mining waste rock survey campaign; end of waste rock processing actions.	Areva	31st December 2017 ; 31st December 2019
VLL waste management		
Methodology and uncertainties associated with the forecast estimates for VLL waste production and decommissioning case studies for each licensee, evaluating the volumes of VLL waste produced according to several post-operational clean-out scenarios.	Areva, CEA, EDF	30th June 2018
Experience feedback from implementing of waste zoning.	Areva, CEA, EDF	30th December 2020
Study on the use of VLL rubble as infill material at the Cires	Andra	31st March 2017
Reutilisation of VLL rubble in the Cires.	Andra	31st December 2018
Technical and safety options for a metal materials processing facility and corresponding reutilisation routes	Areva, EDF	30th June 2018
Comparison between incineration-disposal of residues and direct disposal of incinerable VLL waste	Andra together with Socodei and the producers	30th December 2017
Feasibility of the creation of VLL disposal facilities close to the existing BNI sites	Areva, CEA, EDF, Andra	30th June 2020
Study of VLL repository densification methods	Andra and the producers	30th June 2018
Study of the technico-economic feasibility of melting of VLL metal waste for densification	Producers and Socodei together with Andra	30th June 2018
Application for extension of Cires capacity for the same ground footprint.	Andra	6 years before saturation[224]
Updating of VLL repository acceptance criteria for thorium and uranium-bearing substances.	Andra	31st December 2020
Update of overall industrial system for VLL waste management and proposal of a multi-criteria analysis chart able to demonstrate the pertinence of the choices made for the management of VLL waste, more particularly with regard to the environment.	Andra	31st December 2020

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[224] Provided that the possibility of extending the Cires is confirmed.

Study on the transport of VLL radioactive waste	Areva, CEA, EDF	31st December 2018
Management of LLW/ILW-SL waste		
Preliminary design for a lead processing facility	Areva, CEA, EDF, together with Socodei as necessary	31st December 2018
Study on the transport of LLW/ILW-SL radioactive waste	Areva, CEA, EDF, Socodei	31st December 2017
Management of LLW-LL waste		
(Preliminary) technical and safety options for a near-surface repository for LLW-LL waste	Andra	30th June 2019
Interim report on the LLW-LL repository defining the applicable safety requirements	Andra	30th June 2018
Safety options file (basic engineering design level) for a LLW-LL waste repository	Andra	31st December 2021
Proposed prudent commissioning date for the LLW-LL repository	Andra	31st March 2017
Interim report on processing-decontamination of graphite waste	CEA, EDF	31st December 2017
Technical and safety options (basic engineering design level) for a graphite waste processing facility	CEA, EDF	31st December 2019
Study on the assessment of the chlorine 36 inventory of the graphite waste	EDF	30th June 2019
Interim graphite waste measurement results	CEA	30th June 2019[225]
Overall industrial system for management of LLW-LL waste	Andra together with the producers	31st December 2019
Siting methodology for a new LLW-LL repository	Andra	30th June 2018
Details of storage capacity and strategy for the creation of new capacity for LLW-LL waste	Producers and holders of LLW-LL waste	31st December 2017
Technical and safety options (basic engineering design level) for a storage facility for the graphite waste from the Saint-Laurent des Eaux silos	EDF	31st December 2019
Management of HLW/ILW-LL waste		
Update of the Cigeo calendar, if necessary	Andra	30th June 2017
Evaluation of the acceptability in Cigeo of the waste already packaged	Areva, CEA, EDF	2 years after submission by Andra of the acceptance specifications

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[225] The complete results are required before 31st December 2021.

Evaluation of the behaviour of bituminised waste packages (reactivity and ageing in particular); Impact of this assessment on the Cigeo acceptance conditions	CEA, together with Andra and the owners of bituminised waste; Andra	30th June 2017 ; 30th June 2018
Bituminised waste packages transport modes	Areva, CEA	30th June 2018
Progress of work on the processing and packaging of bituminised waste packages (LLW-LL and HLW/ILW-LL)	CEA	30th June 2018
Technical, economic and safety assessment comparing the various processing and packaging modes envisaged for bituminised waste	Areva, CEA, EDF and Andra	31st December 2019
System for recovery of structural waste and spent GCR fuels stored in Marcoule	CEA	31st December 2017
Report on the development of the PIVIC incineration/vitrification process	AREVA	31st December 2018
Forecast inventory of materials and waste produced by the French reactor fleet according to different scenarios and footprint of these substances in deep geological disposal	CEA	30th June 2018
Study programme to demonstrate the ability of Astrid to multi-recycle the plutonium contained in the spent MOx fuels, to stabilise or reduce the plutonium inventories and transmute americium	CEA	31st December 2018
Technical data on the basis of which the decision to abandon near-surface storage was taken	Andra	31st December 2017
HLW/ILW-LL waste storage needs for the next twenty years	Areva, CEA, EDF	30th June 2017
Update of the plan to provide packagings for waste transport to Cigeo	Areva, CEA, EDF	31st December 2017
Study of the transport of HLW/ILW-LL waste to Cigeo	Areva, CEA, EDF, together with Andra	31st December 2017
Study of management procedures for degraded ILW-LL waste packages removed from the repository	Andra	/
Inventory of waste to be included in the Cigeo reserves	Andra	31st March 2017
Evaluation of the cost of spent fuel disposal in Cigeo	Andra	31st December 2018
Management of waste requiring specific work		
Acceptability of mercury waste stabilised by sulphur in the existing repositories	Andra	31st December 2017
Continuation of the studies into the processing/packaging processes for the other types of mercury waste for which no management route has yet been defined.	Areva, CEA, EDF	/

Progress briefing on the development and implementation of the processes envisaged for treatment of organic oils and liquids	Areva, CEA	31st December 2017
Study of the acceptability of the liquid and organic waste in their possession in the routes set up by Areva and CEA.	EDF, Andra	/
Progress made in management of activated waste from the small producers.	Andra	31st December 2017
Comparison of different management solutions for different types of tritiated waste: storage, incineration, direct disposal.	CEA, Socodei together with Andra	31st December 2017
Study of the possibility of its facilities accepting tritiated waste from defaulting responsible parties for storage or disposal	Andra	31st December 2020
Progress report on the search for appropriate management routes for gaseous and liquid tritiated waste from small producers outside the nuclear power sector	Andra	31st December 2019
Strategy envisaged for the management of solid tritiated waste from the small producers, pending the commissioning of storage facilities planned for ITER.	Andra	31st December 2017
Presentation of the deployment of management solutions for used sealed sources considered as waste	Andra	31st December 2017
Progress report on the search for final management solutions for waste stored in the ECRIN BNI	Areva	31st July 2020
Management strategy for the desiccated sludges currently produced by the Malvési plant and which will not be stored in the ECRIN BNI	Areva	31st December 2017

Appendix 2: Societal aspects, concepts and plans for the post-closure period of radioactive waste repositories, preservation of memory

The goal of research in the human and social sciences is to integrate a societal dimension into the various waste management projects and ensure that they all work together in a cross-disciplinary system. The studies conducted more particularly concern the management of the most radioactive waste, which raises complex questions as to the need to address events over long time-scales. The question of long-term preservation and transmission of memory, beyond closure of the repositories, must notably be planned for well in advance.

Societal aspects

The involvement of the Human and Social Sciences (HSS) in the field of radioactive waste and materials management is justified upstream by the desire to make the various recommended solutions more robust. Their acceptability, which in the end is political in nature, is made easier when all the phenomena involved are dealt with in an appropriate framework, without ignoring their socio-economic, environmental, political, cultural, etc. aspects, and the various scientific and technical issues involved are interconnected. One-dimensional, inward-looking R&D has little chance of helping technical projects succeed, as is shown by the history of nuclear waste management in France prior to 1991. The aim of HSS research is thus to integrate the social aspects into the various on-going projects and ensure that they all work together in a cross-disciplinary system. Collaboration with researchers from these diverse backgrounds must from the outset aim to create specialised communities on subjects of common interest with the operators and the stakeholders.

Andra's research in the Human and Social Sciences (HSS) focuses on the societal dimensions (socio-economic, political, cultural, etc.) of the Agency's projects and thus aims to improve their robustness from a cross-disciplinary perspective. Focus was therefore placed at first on the topic of reversibility, leading to a number of scientific events and publications, as well as a doctoral thesis in economic sciences. Andra is currently looking to develop this approach on a long-term basis by setting up a group of cross-cutting human and social sciences laboratories around the generic topic "transmission between generations and comprehension of long time-scales". The choice of this topic can be justified by the fact that the time-frames involved in Andra's activities, in particular in the management of the most highly radioactive waste, is indeed unique when compared with other industrial areas. This specificity raises particularly complex questions which notably concern the ability to anticipate events over long periods of time and to ensure that they are managed.

Other research topics, the definition of which is as yet less well-advanced, could be incorporated into this framework in the near future, more specifically in the fields of long-term economics and environmental assessments, or identified by the new HSS programmes which are currently being set up at CNRS and IRSN.

The CNRS's NEEDS programme (Nuclear, Energy, Environment, Waste, Society) includes HSS in the examination of nuclear issues and envisages looking at the question of time in a more general manner, from the risk management and assessment viewpoint. This programme also intends to build on the HSS knowledge acquired on the topic of nuclear waste, more specifically through the considerable work done on this question at CNRS.

The areas of research at Andra and the CNRS are detailed in the research part in appendix 3 of the PNGMDR.

Concepts and plans for the post-closure period

Case of Installations Classified on Environmental Protection grounds:

Industrial centre for collection, storage and disposal (Cires)

The operation of the VLL waste disposal centre in the Cires is regulated by order 2012-040-0002 authorising the operation of this first installation classified on environmental protection grounds dedicated to the disposal of radioactive waste. This order is derived from the regulations applicable to the disposal of hazardous waste (ministerial order of 30th December 2002, amended). Andra also wanted to follow the same methodology for assessment of the long-term impact of the VLL waste disposal centre as that already used for the low and intermediate level waste disposal centres, the Manche disposal centre and the LLW/ILW waste disposal centre in the Aube.

The order thus presents the requirements of resources imposed on the hazardous waste disposal facilities by the regulations as well as the additional requirements specified as a result of the safety assessments carried out for all the phases in the lifetime of the facility, from the construction phase to the post-oversight phase.

In accordance with the authorisation order, Andra will propose a project to the Prefect defining the institutional controls to be applied to all or part of the facility, no later than one year after the end of the operating period. These institutional controls could prohibit the building of constructions and structures liable to impair the conservation and oversight of the site covering. They should also ensure that the means of collecting leachates before sealing of the shafts at the end of the oversight phase are protected and that confinement of the waste emplaced is durably maintained. Moreover, the purpose of the oversight phase will be to monitor the evolution of the disposal facility for a period of at least thirty years after the last waste is emplaced, and its conformity with the forecasts and the order of the Prefect. For this purpose, controls will be maintained, more specifically:

- regular upkeep of the site (ditches, cover, ponds, fencing, etc.);
- geotechnical observations of the site, with regular and at least annual updating of the topographical survey;
- periodic measurement of the quality of the water collected from the centre and discharged into the environment and checks on compartments of the ecosystem in the near environment of the VLL waste disposal centre.

All of these measurements will be to verify the absence of radioactive or chemical pollution in the environment of the centre. They will be able to ensure early detection of any behavioural anomalies and anticipate any remediation measures.

Following this oversight phase, the continued recorded trace (memory) of the centre will at the very least consist of institutional controls entered into the land registry.

Case of Basic Nuclear Installations:

The legislative framework applicable to Basic Nuclear Installations for the period after closure of the facilities, is more specifically based on:

- the energy transition for green growth Act (TECV, Act 2015-992 of 17th August 2015) which specifies the provisions concerning the final shutdown and decommissioning of radioactive waste disposal facilities (article 127);
- the Act on transparency and security in the nuclear field (TSN Act 2006-686 of 13th June 2006 codified) which specifies that the transition of a BNI to the oversight phase is subject to authorisation (Article L. 593-25 of the Environment Code) and that the administrative authority can apply institutional controls around this BNI (Article L. 593-5 of the Environment Code);
- decree 2007-1557 of 2nd November 2007 which specifies the content of the authorisation application file for transition to the oversight phase. This file in particular contains: the impact assessment, a safety report, a risk management study, the general oversight rules and, as applicable, the institutional controls (see Article 43 of this decree);
- the order of 7th February 2012 setting out the general rules for BNIs. Chapter V of this order concerning radioactive waste disposal facilities stipulates that: "In compliance with the objectives set forth in Article L. 542-1 of the Environment Code, the choice of the geological environment, the design and the construction of a radioactive waste repository, its operation and its entry into the monitoring and surveillance phase are defined such that protection of the interests mentioned in article L. 593-1 of the Environment Code is ensured passively against the risks presented by the radioactive or toxic substances contained in the radioactive waste after entry into the monitoring and surveillance phase. This protection must not require intervention beyond a limited monitoring and surveillance period, determined according to the radioactive waste disposed of and the type of repository. The licensee justifies that the chosen design meets these objectives and justifies its technical feasibility".

The Manche repository

From the regulatory viewpoint, the Manche disposal facility (CSM) is a basic nuclear installation (BNI n°66) dedicated to the surface disposal of low and intermediate level, short-lived waste. The creation authorisation decree dates from June 1969. The installation's transition to the monitoring and surveillance phase was authorised by decree 2003-30 of 10th January 2003. This monitoring and surveillance phase is conventionally scheduled for a period of three hundred years and comprises releases license dated 10th January 203. In 1996, on the basis of the conclusions of the Manche repository situation assessment commission (known as the "Turpin Commission"), it was decided that the "site could not be simply ignored" after this monitoring and surveillance period. Andra thus confirmed the need to maintain and eventually transmit the memory of the site and take all necessary steps to limit the nature of the constructions or equipment which could be installed on it.

The concepts and plans for the post-closure period comprise: the design of the facility, monitoring/surveillance and maintaining a recorded memory:

- measures concerning the design were taken by the licensee during the operating phase. Thus, after closure, the disposal facility corresponds to a mound in which the waste packages disposed of in the structures are protected from climatic hazards by a low-permeability cover; an effluents management system recovers water that has infiltrated through the cover and/or into the disposal facility. The water recovered is transferred to the Areva-La Hague treatment installation, in accordance with the discharges authorisation order;
- decree 2003-30 authorising transition to the monitoring and surveillance phase mentioned that the licensee must ensure monitoring and surveillance appropriate to the facility and its environment. This is defined in the regulatory monitoring and surveillance plan, which includes monitoring of the cover, the confinement of the disposal structures and the discharges from the centre. This plan specifies that the results are regularly sent to ASN (annual report) and to the public (summary of the annual report presented to the CLI). The decree also defines that protection of the facility against the risks of intrusion and malicious acts is guaranteed for the duration of the monitoring and surveillance phase. Furthermore, the decree stipulates that every ten years, the licensee shall study whether or not the monitoring/surveillance and protection measures applicable to its facility need to be updated;
- in terms of maintaining a memory and record of the facility, three avenues have been identified:
    - long-term archival of the information: decree 2003-30 defines the requirements concerning the long-term archival of information:
        - detailed memory: the documents are duplicated on permanent paper and archived in two separate places, in the Manche disposal facility and in the French National Archives. The archive is updated every 5 to 10 years depending on developments in the Centre;
        - summary memory: an initial version of this document of about a hundred pages was submitted to ASN and the CLI in 2008. This document should be revised as and when the safety reviews are carried out, in order to incorporate all the operating experience feedback gained from the monitoring and surveillance phase. When it is considered as having been stabilised, it will be printed on permanent paper and widely distributed, as stipulated by the technical prescriptions;
    - information of the public, in particular during the monitoring and surveillance phase, more specifically via exchanges with the CLI and through communication measures;
    - the draft application for the creation of institutional controls to minimise the risk of intrusion into the disposal facility for as long as possible after the monitoring and surveillance phase. Such institutional controls were suggested by the Turpin Commission and envisaged by Andra, in the 2009 safety report, pursuant to Article 31 of Act 2006-686 of 13th June 2006.

The Aube waste disposal facility

From a regulatory viewpoint, the Aube LLW/ILW waste disposal facility, which took over from the Manche disposal facility, is also a basic nuclear installation (BNI n°149). The creation authorisation decree of 4th September 1989, was modified by decree 2006-1006 of 10th August 2006 plus its discharge license of 21st August 2006.

With regard to the post-operation period, the creation authorisation decree for the LLW/ILW waste disposal centre notably stipulates that: (i) during the monitoring and surveillance phase, "the structures shall be protected by a cover of very low permeability" and "the facility shall continue to be monitored for a time allowing radioactive decay of the radionuclides with short or intermediate half-lives, to a level presenting no further significant radiological risk." (ii) following the monitoring and surveillance phase, "it shall be possible for the land occupied by the facility to be used normally without any radiological restriction […] no later than 300 years after the end of the operating phase".
In addition to the regulatory aspects, Andra also follows the recommendations of RFS I.2 which defines the fundamental safety objectives for surface facilities intended for the disposal of LLW/ILW-SL solid radioactive waste, in particular the design bases for a repository and the monitoring of the facility during the operations and monitoring/surveillance phases.

In the same way as the CSM, the concepts and plans for the LLW/ILW waste disposal centre's post-closure period comprise: the design of the facility, monitoring/surveillance and maintaining a recorded memory:

- the measures concerning the design are taken by the licensee during the operating phase in accordance with the requirements of RFS I.2:
    - the limitation of initial activity: the radioactive waste accepted by the LLW/ILW waste disposal centre is waste with a short or intermediate half-life, with limited quantities of long-lived radionuclides or those with low or intermediate specific activity. The aim is for the activity of the radionuclides disposed of to have significantly decreased during the 300 years of facility monitoring and surveillance;
    - the containment of the waste is ensured by the packages and the structure during the operating phase, to which are added the cover and the infiltrated water collection networks during the monitoring and surveillance phases and by the geological formation on which the repository is installed, in particular in the phase subsequent to monitoring and surveillance;
- the provisions concerning monitoring and surveillance of the facility and its environment. At closure of the centre, in accordance with decree 2007-1557, Andra will apply for authorisation to make the transition to the monitoring and surveillance phase and shall propose general monitoring and surveillance rules. A decree will authorise transition to the monitoring and surveillance phase. The monitoring approach currently employed during the operations phase will in principle continue during the monitoring and surveillance phase. This monitoring and surveillance relies on a certain number of measurements (notably radiological, chemical, water table heights, hydrological, climatological) the monitoring of which over a period of time should make it possible to: (1) verify the correct working of the disposal facility, ensuring the absence of any unacceptable dissemination of the radionuclides initially contained in it; (2) detect any abnormal situation or development in order to identify and locate the causes and initiate the necessary remedial measures; (3) gain sufficient understanding of the repository evolution mechanisms; (4) assess the radiological and chemical impact of the repository on the population and the environment and monitor its evolution, in order to verify compliance with regulatory requirements; (5) ensure protection of the facility against the risks of intrusion and malicious acts;
- provisions concerning maintaining the recorded memory: Andra relies on the reference solution developed for the CSM, for which preparations are made as of the operations phase. The CLI should also continue during the monitoring and surveillance phase and thus allow public information and consultation.

The Cigeo disposal facility project

The Safety Guide for the final disposal of radioactive waste in a deep geological formation was issued by ASN in 2008. This guide defines:

- the fundamental safety objective: protection of the health of individuals and of the environment as the fundamental safety objective of the disposal facility. After closure of the repository, the protection of individual health and the environment must not depend on monitoring and surveillance and institutional controls which cannot be maintained with absolute certainty beyond a limited period;
- the design bases and safety principles;
- monitoring/surveillance and maintaining the recorded memory: a facility monitoring and surveillance programme must be put into place during the construction of the disposal structures and until closure of the facility. Certain monitoring and surveillance provisions could also be maintained after closure of the facility. The need to implement this monitoring and surveillance should be taken into account as of the design of the disposal system. The recorded memory must be maintained after closure of the site.

The Cigeo disposal project will be designed in a deep geological layer, the Callovo-Oxfordian, to allow long-term confinement of the substances contained in the High Level and Intermediate Level long-lived waste. According to Article L. 542-10-1 of the Environment Code, *"a disposal facility in a deep geological formation for radioactive waste is a basic nuclear installation"*. The Cigeo project thus falls under the regulations applicable to BNIs, as defined in part 1 of this PNGMDR.

In accordance with the regulatory framework, notably the order of 7th February 2012, and the above-mentioned ASN Safety Guide, the Cigeo disposal facility project is designed to evolve from active safety to entirely passive safety, where no human intervention will be required. After operation, the facility will be closed and enter the monitoring and surveillance phase.

As with surface facilities, the concepts and plans for the period following closure of the planned Cigeo disposal facility comprise the design of the disposal installations, monitoring and surveillance and maintaining the recorded memory:

- provisions concerning the design: to meet the post-closure safety objectives, the deep geological formation disposal facility is designed to be able to guarantee and demonstrate safety during operations and for a long time following its closure, with regard to both man and the environment, while being reversible for a period of at least 100 years. In accordance with the regulations and the ASN Guide, the underground disposal facility shall, once closed, meet the post-closure safety objectives passively. The safety of the facility is thus based on a range of components for confining the radioactivity and isolating the waste from any possible external hazards;
- the provisions concerning monitoring and surveillance of the facility and its environment. Steps shall be taken to maintain the memory and ensure monitoring and surveillance for as long as possible. Monitoring of the environment is envisaged prior to construction (initial baseline state), during construction and throughout the operating period. This could be continued after closure of the underground facility and decommissioning and dismantling of its operating installations on the surface. This monitoring and surveillance will meet the regulatory requirements concerning the monitoring of the impacts of the facility. The purpose of these measurements will be to verify the absence of radioactive or chemical pollution in the environment of the centre and ensure that it is functioning correctly. The long-term environment observatory (OPE) offers a framework for monitoring the environment before and during

construction and operation. A monitoring and surveillance programme is also designed with respect to post-closure safety, to monitor a certain number of parameters in the underground facility during its operating phase. The means implemented for post-closure monitoring and surveillance of the Cigeo project will notably be based on experience feedback from the surface facilities;
- provisions concerning maintaining the recorded memory focus primarily on: transmission to future generations, to inform them of the existence and contents of the facility and provide them with knowledge enabling them to understand their observations, to facilitate any actions or to transform the site. At present the reference solution adopted by Andra to guarantee the memory of its disposal centres (see specific section below) is based on five measures: (i) three "active" memory systems to ensure that a recorded memory is preserved in the short and medium terms, and (ii) three "passive" systems for the longer term. This reference arrangement must be implemented for the Cigeo disposal project, with the need for the memory to be maintained following closure of the facility for as long as possible, and at least for five centuries. At this stage of the project, the reference solution implemented in the Manche disposal facility constitutes the basis for the memory system to be implemented for the Cigeo repository project.

Low level, long-lived waste disposal project

Andra draws on the "General safety orientations report concerning the search for a site for disposal of long-lived waste of low specific activity" published by ASN in May 2008. It thus stipulates that:
- after closure of the disposal facility, protection of the health of individuals and the environment should not depend on monitoring/surveillance and institutional controls, which cannot be maintained with any degree of certainty beyond a limited period;
- with regard to the monitoring and surveillance phase, the designer must examine the means of ensuring this monitoring and surveillance as of the design of the disposal facility.

The concepts and plans for the period following closure of the LLW-LL project are closely linked to the concepts developed, to the site(s) chosen for the disposal facilities and to the nature of the waste disposed of. Steps shall be taken with respect to monitoring and surveillance following closure of the disposal facility. They shall be studied and clarified as the design studies progress. They shall be based on all the operating experience feedback from the licensee, Andra, concerning the other centres.

Preservation and transmission of the memory of Andra's repositories

All the Andra repositories currently operated or planned make provision for the preservation of memory, so that a record of these repositories can be handed down after their closure. The question of the long-term preservation and transmission of a recorded trace, after closure of the disposal repositories, is quite different from that of managing the knowledge needed for a conventional industrial project. This type of knowledge management system is used by Andra and elsewhere and will necessarily evolve over the coming decades. This evolution cannot however guarantee the transmission of knowledge or even of a trace of the repository over the very long term, especially once no repositories are in activity any more. It is therefore necessary to anticipate what future generations would need in order to preserve a memory of the repository, if the evolution of the knowledge management system were to prove insufficient to keep it operational.

The reference solution implemented by Andra:

The problem of maintaining the memory of the disposal facilities was considered as of the 1980s for the Manche repository (CSM). To address this problem, a solution of archival on permanent paper was defined in 1995. In 1996, the Turpin commission confirmed the methods adopted by Andra and recommended further new developments. The reference solution chosen by Andra for the long-term record of its disposal facilities is currently built around three "passive" and three "active" records.

The three "passive" records are:

- the "detailed record" consisting of all the technical documentation necessary for the monitoring and surveillance, comprehension and modification of a disposal facility. The creation of the detailed record is based on the selection and ranking of information by means of possible evolution scenarios identified consistently with the long-term safety approach. A set of search instruments (inventories, glossary, index, abstracts, etc.) ensure accessibility and understanding. The sustainability of the documents is based on an appropriate choice of the "permanent ink/paper" combination and the conservation of two copies on separate sites, the repository itself and the National Archives. Finally, the validity of the detailed record is updated by additions every five years, until the end of the monitoring and surveillance phase;
- the "summary record" is a single document summarising the technical and historical information, intended for the decision-makers and the public. Updates are planned after each revision of the safety analysis reports. The full informative weight of the final version will depend on its widespread distribution: town halls, lawyers, associations, General Council, Prefect's office, Ministries, national and international institutions, etc.;
- entry on the registry of "institutional controls" ensures that there is an administrative record of the site, giving warning of a potential risk if carrying out works on it.

The three "active" records are:

- the ten-yearly assessment of the passive memory records, to ensure that they will meet the needs of future generations, as we currently imagine them, but also to create a permanent "memory ritual";
- the development of communication with the public thanks to the organisation of open days, conferences, exhibitions and interviews, as well as by distributing specific memory communication tools, brochures and website;
- increasing the role of the local information committees (CLI). The question of memory is one of the topics tackled by these committees, which should enable it to be discussed and debated at the local level.

Analysis of this system as a whole, more specifically in the light of experience feedback on the durability of other historical memory systems, leads to the conclusion that there can be a high degree of confidence that it would last for several centuries. This reference solution also complies with regulatory requirements applicable to the various repositories of radioactive waste.

Andra's memory record programme:

Without more detailed examination, the reference solution adopted by Andra cannot however be considered as being the best available solution. It in fact comprises certain weak points. It is heavily biased towards the conservation of documents and does not give sufficient consideration to other media. Furthermore, no detailed study of its compatibility with the potential needs of future generations has been carried out. Finally, a record that is guaranteed for "only" a few centuries after closure of the repository is considered to be too short by several stakeholders in this repository, notably for the future local residents. Consequently, in 2010, Andra decided to launch a memory project with a two-fold goal: increase the robustness of the reference solution and look at possibilities for a recorded memory designed to last several thousand years.

The memory programme comprises on the one hand work designed to continue to create and improve records about the facilities and, on the other, scientific studies concerning two fields: materials ageing and human and social sciences (also see appendix 3 to this PNGMDR).

With regard to creating and improving a memory of the centres, the following work has been started:

- the pertinence of the memory system for the Manche disposal facility in the light of the needs of future generations is analysed every ten years by a group of international stakeholders, in order to periodically examine its adequacy and its comprehensiveness. An initial exercise of this type was carried out in 2012 and identified a number of improvements that could be made to the system;
- preparations for recording the memory of the Cigeo geological disposal project are under way: creation of the detailed memory of the Meuse / Haute-Marne underground laboratory and other elements concerning preparations for the creation of Cigeo (from among everything produced since the early 1980s select that which needs to be kept as data used to substantiate the decision to create Cigeo);
- the "technical" usefulness of the memory must be better explained, on the one hand to specify the benefits of this record for long-term safety and on the other to clarify the reversibility requirement;
- around these sites, Andra proposes setting up think tanks to interest the local populations in this problem, but also to collect their ideas about how they could address it locally;
- collaborations with a number of French and international artists are organised, in various artistic fields, in order to obtain their vision of the problem of recording the memory of the repositories through their art;
- Andra takes part in international work on memory as part of the NEA/RWMC/RK&M working group (benchmark practices in various participating countries, joint definitions and bibliography, and drafting of recommendations);
- the creation of spaces dedicated to this memory is envisaged (in Andra's public visitor centres, study of the creation of a historical archive centre with delegation to the Archives de France).

Scientific studies into the ageing of materials consisted in testing the permanent ink/paper combination by means of standardised tests. Durability studies on other media for the longer term are currently being defined. They will concern non-paper media for writing and engraving, in particular studies of surface markers to be installed on the cover over the centres and the production of sapphire disks as demonstrators for a memory medium, the longevity of which could be up to a million years.

With regard to HSS, a group of laboratories was created to study perception of long time scales. For the other subjects linked to HSS (archives, linguistics, museography, archaeology of techniques and landscapes, etc.), a three-stage approach is planned: a succinct bibliography designed to show whether works already exist and are sufficient, otherwise a detailed bibliography produced with universities in order to determine any research that is to be incorporated into the scientific programme. The work will in particular concern continuity, temporality and vestiges, as well as the social dimension of the problem.

Continuity will in particular be studied through:

- languages and symbols, in order to determine for what reasonable time current or dead languages can be known and what the communication solutions could be once these languages cease to be known;
- institutional conservation of written works, sounds, images, objects, etc. by specialised French and international organisations, to analyse the preventive measures taken to limit deterioration over time and encourage assimilation and transmission by future generations;
- long-term digital archival, more specifically by organising an intelligence watch in this field, which is beginning to become organised and which, within the next few decades, could open up new prospects for the long term.

Temporality and vestiges will be more specifically studied through:

- the archaeology of techniques and landscapes, incorporating man-made changes and geodynamic changes, as well as the possibilities of memory resulting from the permanence of infrastructures created by Man;
- the memory of “legacy” repositories not managed by Andra, which exist in various places in France (uranium mines, nuclear tests, etc.).

The social dimension will in particular be studied through:

- the perception by the public of long time scales (several thousand years and more), within the framework of the grouping of human and social sciences laboratories;
- the three possible directions of social change in science, technology, humanity, etc. (regression, stagnation, progression);
- the integration of repository memory preservation into teaching programmes on nuclear energy, heritage and memory;
- the transmission of memory between generations via internet social networks to provide global information about the memory and records of the repositories.

The memory project comprises a number of milestones corresponding to the deadlines of the Cigeo and LLW-LL disposal projects and the periodic safety reviews of the repositories in operation. It will be extended to accompany the development of these repositories and their monitoring/surveillance and closure phases, so that it remains fully operational during the post-surveillance phase.

Appendix 3: Summary of accomplishments and research carried out in other countries

Summary of accomplishments in other countries

This summary presents accomplishments abroad concerning the management of radioactive materials and waste (countries concerned: Belgium, Canada, China, Finland, Germany, Japan, Netherlands, Spain, Sweden, Switzerland, United Kingdom and the United States). The notion of "accomplishment" is considered relatively broadly, including not only the drafting of the legal framework and the definition of a classification of radioactive waste, but also the development of management programmes.

Drafting of a legal framework

Radioactive waste management plans (similar to the PNGMDR to varying extents) sometimes exist abroad, but with objectives that vary significantly from one country to another. Furthermore, some of these plans are not made public.

In Europe, European directive 2011/70/Euratom of 19th July 2011 concerning the responsible and safe management of spent fuel and radioactive waste requires the establishment of national programmes specifying how the member States implement their national spent fuel and radioactive waste management policies. The content of the national programmes, set out in article 12 of the directive, more specifically comprises an inventory of spent fuels and radioactive waste, the general objectives to be reached, the financing mechanisms and an estimate of the cost of the programme. This directive thus harmonises the European framework for the management of spent fuel and more specifically the establishment every three years of the national programmes, the first version of which must be transmitted to the European Commission in August 2015.

In the United States, following the 2009 decision to suspend the high level waste and spent fuels disposal project envisaged at Yucca Mountain, a new approach was run by the DOE, entrusting the recently created Blue Ribbon Commission (BRC) with a review of the management strategy for spent fuels and HLW waste and the proposal of plans to underpin future Government actions. Pursuant to the BRC's recommendations, the DOE notified its spent fuel management strategy in January 2013. It provided for a pilot storage facility that could be in service as of 2021, followed by storage of at least 20,000 tons (U metal) in 2025, situated either on the pilot site, or on the candidate site for the geological repository. The commissioning of a future geological repository for spent fuels was announced for 2048. The implementation of this programme however requires the definition of an institutional and legal framework, which must set a calendar and formulate siting requirements. The law will thus specify the creation of a new organisation for implementation of the programme.

In 2001, the United Kingdom published a White Paper entitled *"Managing Radioactive Waste Safely - proposals for developing a policy for managing solid radioactive waste in the UK"*, which announces a waste management plan and organisation. 2008 saw the publication of the White Paper entitled "*Managing Radioactive Waste Safely: A Framework for Implementing Geological Disposal*" (MRWS). It defines a framework for implementing deep geological disposal of high level radioactive waste. This framework more specifically makes provision for active collaboration with any local authorities prepared to host the facility. In 2014, a new White Paper entitled "*Managing Radioactive Waste Safely - Implementing Geological Disposal*" updated and superseded the 2008 White Paper. This document establishes a reinforced general framework for the implementation of geological disposal and identifies the first steps to be taken by the Government of the United Kingdom and the designated manager (Radioactive Waste Management Ltd., a wholly-owned subsidiary of the Nuclear Decommissioning Authority) to support the geological repository siting process. This in particular entails providing the candidate host authorities with more detailed, clearer information on the key questions.

With regard to inventory, practices vary widely, particularly concerning scope (inclusion of a VLLW category in France, the inclusion of mining waste in the United States), exhaustiveness and the level of detail (less detailed in Germany than in France), distribution to the public (the inventory is not public in Spain; in Japan the producers are free to make their own inventories public or not), the frequency of updating and the coverage of waste referred to as "engaged" given the current rate of production (until 2080 for Germany, but in the United States for instance, engaged waste is not included).

Despite the work done by IAEA (which provides a common database to all countries - NEWMDB, but with a relatively global approach involving very broad waste categories), comparisons remain difficult, in particular because the units of reference (volume, weight, etc.) used to measure the quantities of radioactive waste, differ from one country to another. The computerised data remote-collection tool used by the Member States who signed the Joint Convention is being upgraded to allow a declaration in the national classification to be automatically converted to the IAEA classification.

As in France with Andra, a public organisation is responsible for implementing the management of radioactive materials and waste in Belgium (ONDRAF-NIRAS) and in Spain (ENRESA). There is a public organisation in the Netherlands, COVRA, but it is not really comparable, be it in terms of scope of waste covered, or in terms of activities. However, the waste producers (especially the private ones) are most often directly responsible for practical implementation of waste management. They then create a cooperative to manage certain waste, jointly with the public producers: Canada (NWMO-SGDN), Finland (Posiva Oy, for spent fuel only), Sweden (SKB), and Switzerland (CEDRA-NAGRA, which does not manage storage). Sometimes, there is no centralised organisation, notably in Japan, where each type of waste corresponds roughly to its own management route and organisation. It should be noted that these organisations are far from always being the "owners" of the waste they have to manage: in Canada, the producer remains responsible, even after closure of the disposal facility; in the United States, the State is responsible for civil waste as of the transport phase (followed by the disposal after burial and disposal after site closure phases).

The list of organisations in charge of radioactive waste is given in the following table:

Country	**Organisation**		**Status**	**Date of creation**	**Remarks**
Germany	BFS	Bundesamt für Strahlenschutz	Govern-mental (BMU)	1989	
Belgium	ONDRAF/ NIRAS	National organisation for radioactive waste and enriched fissile materials	public	1980	
Canada	NWMO	Nuclear Waste Management Organization	private	2002	Geological disposal of SF*
China	EEE/CNN C	Everclean Environmental Engineering Corp./China National Nuclear Corporation	public	1995	EEE disposal LLW/ILW waste
South Korea	KORAD	Korea Radioactive Waste Agency	public	2013	Following on from KRMC set up in 2012
Spain	ENRESA	Empresa Nacional de Residuos Radiactivos, S.A.	public	1984	
United States	DOE Nuclear Energy	Department of Energy	Govern-mental	1982 (for SF)	Disposal of SF*
Finland	POSIVA	Posiva Oy	private	1995	Geological disposal of SF*
France	ANDRA	French national radioactive waste management agency	public	1991	
Japan	NUMO	Nuclear Waste Management Organization of Japan	public	2000	Final disposal of HLW waste
Netherlands	COVRA	Centrale Organisatie Voor Radioactief Afval	public (since 2002)	1982	
United Kingdom	NDA	Nuclear Decommissioning Authority	public	2005	
Sweden	SKB	Svensk Kärnbränslehantering AB	private	1970s	
Switzerland	NAGRA	Nationale Genossenschaft für die Lagerung radioaktiver Abfälle	private / public	1972	

Organisations in charge of radioactive waste
**SF: Spent fuels*

With regard to the financing of radioactive waste management, the polluter-pays principle would seem to be universally applied for management of radioactive waste facilities, but not for waste management research.

It should be noted that all the countries mentioned here (except for China, which is currently in the process of joining) are members of the IAEA Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management, which entered into force on 18th June 2001. These countries meet in Vienna every three years under the auspices of IAEA, to present their national reports describing the implementation of their obligations and any developments. The last meeting of this type was held in May 2015.

Waste classification

The different types of classifications

There are two main approaches to defining the classification of radioactive waste: one approach based on the waste management route and one on the waste production route (this latter approach being in part inherited from the historical construction of radiation protection, generally built around the individual production routes).

Within the first approach (by management route), the classification abroad, in the same way as in France, often combines the activity and lifetime parameters of the radionuclides making up the waste (for example Belgium, Spain).

However, the waste classification is sometimes based solely on the activity level. For example, in Canada, there are only two main categories (LLW/ILW-SL and HLW, including spent fuels), except for the specific management of mining waste. In the Netherlands, the classification comprises a larger number of categories, but there is no distinction between short-lived and long-lived waste; consequently, there is no surface disposal project.

Other classifications sometimes exist (leading to categories that are qualitatively comparable but which have quantitatively different thresholds): Germany for example has based its classification primarily on the exothermic nature of the waste.

In countries which adopted the second approach (by production route), the classification is more complex, with routes specific to certain types of waste and combining activity and lifetime: United States, Japan and Sweden (in this last country the two types of approach in fact co-exist). Finally, a category is sometimes added for waste from hospitals, universities, etc., for example in Finland.

In addition, certain categories correspond to specifically national characteristics: Belgium (processing of 50% of the radium sources used worldwide) and Canada (large-scale uranium mining).

Finally, the absence of clearance levels in France (for waste which contains or which is liable to contain only very small quantities of radioactive elements) is specific to this country. Such levels exist in the other countries studied, but vary considerably both in terms of the level itself and the scope of waste considered; the VLLW category therefore rarely exists in its own right and does not correspond to the same waste as in France.

Waste classification adopted by the IAEA

In late 2009, IAEA published a wide-ranging revision of the radioactive waste classification which dated from 1994 (IAEA, 2009). It is used by the member countries for an international presentation of their radioactive waste management and their inventories, such as for example in IAEA's NEWMDB database. The European Union refers to it in the directive on the responsible and safe management of waste and spent fuels of 19th July 2011.

This revision was felt to be necessary because the classification system previously defined by IAEA was not exhaustive: it did not cover all types of radioactive waste, nor did it provide a direct link with the disposal and management options for all types of radioactive waste. These shortcomings in the former classification proved to be obstacles to its utilisation and its application.

The new 2009 classification system introduces a new category of waste - VLLW (Very Low Level Waste) and uses the LLW (Low Level Waste), ILW (Intermediate Level Waste) and HLW (High Level Waste) classes. These classes take account of both the level of radioactivity and the half-life of the radionuclides contained in the waste.

In it, the waste are classified according to the degree of confinement and isolation required to guarantee long-term safety, based on their nature and the risk they represent. This waste classification allows an incremental approach to obtaining the required level of safety, because it is based as much on practices as on the characteristics of the sources, the levels of exposure to which they lead and their occurrence.

Management routes that exist or are under construction

Choice of the type of fuel cycle

The decision to reprocess spent fuels was taken in various countries in the 1950s for military purposes and at the end of the 1970s for civil uses. A certain number of countries today have facilities:

- for the complete processing of fuels, as in France, the United Kingdom and Japan (for which industrial start-up has however not yet been declared and which could be postponed indefinitely);
- for processing of fission products in the United States as part of the clean-out of former sites such as Hanford, or for separation in Russia to retrieve reusable materials from spent fuels;
- for research as in China, which also opted for a closed fuel cycle, but which is developing test facility projects, notably with the help of France, and in India which is building a pilot plant for the vitrification of fission products.

Several other countries which do not have dedicated facilities on their own territory had or indeed still have all or part of their spent fuels processed in plants abroad, mainly in the United Kingdom and France, this particularly being the case of Germany, the Netherlands, Switzerland and, to a far lesser extent, Spain. Some of the Eastern European nations also do the same in Russia. Some of these countries have however decided to put an end to processing abroad at some time in the near or not so near future: Germany and Switzerland in particular have made a legislative commitment to this and Belgium has for the time being suspended its waste processing contract with the La Hague plant.

For the time being, South Korea has not made a final decision concerning the processing of its light water reactor fuels, which are currently stored on the production sites.

The other option currently being used is to directly manage the spent fuels without any separation or processing phase. This is used in Canada, Finland and Sweden. This has also been the case in Spain and the United States since the implementation of non-proliferation arrangements in the 1980s (under President Carter).

Decommissioning activities

The countries which have operated nuclear power generating, research or fuel cycle facilities for half a century have initiated major decommissioning programmes for the older facilities, along with post-operational clean-out of the sites. In recent decades, the United States has been carrying out a programme concerning 108 sites covering a total surface area of 800,000 ha. In 2005, the United Kingdom created the Nuclear Decommissioning Authority for eventual decommissioning of all existing nuclear facilities. Decommissioning generates a considerable volume of waste, mainly VLLW waste but also LLW/ILW waste. Its management requires rigorous technical planning and available financing.

Management of LLW/ILW waste and LLW-LL waste

In several countries, surface or near-surface disposal centres for LLW/ILW waste are already in operation. They were created to accompany the production of energy of nuclear origin: in China, the Beilong and Diwopu disposal centres, in Spain that at El Cabril, in the United States the centres in Barnwell, Richland, Clive and Andrews, in Finland those of Olkiluoto and Loviisa excavated into the granite at a depth of 60-100 m, in Japan that of Rokkasho-Mura, in the United Kingdom that of Drigg opened in 1959 (about 1,000,000 m^3 are emplaced in it in trenches and on platforms), and in Sweden the SFR centre in Forsmark located 50 metres under the Baltic Sea.

Others are under construction or design in specific locations and the projects differ widely, in terms of the type of site chosen, the design of the disposal centre and its depth. These factors ultimately determine the type of waste that can be disposed of (particularly with regard to the lifetime). Thus, in Belgium, the Dessel disposal centre, which was to enter service in 2022, will in fact only accept short-lived LLW/ILW waste. Of the other projects under construction or planned, the following geological repositories are particularly noteworthy: that planned for about 2020 in Kincardine, Canada at a depth of 680m near the Bruce reactor (Ontario) and that in Germany, as of 2019, for LLW/ILW in the old Konrad iron mine in Salzgitter, at a depth of about 1000 m. In the United Kingdom, the construction of 2 of the 4 disposal structures eventually planned was completed in May 2015 on the Dounreay site.

However, several countries have not completed or defined their LLW/ILW waste disposal project, such as Switzerland and the Netherlands, but also Italy, which has undertaken the disposal of the waste from its shutdown facilities. Others are closing old sites and reconsidering new locations, as in Germany, concerning the Asse and Morsleben sites.

More specifically with respect to LLW-LL waste, current management abroad consists primarily in storing it on the production sites. Long-term management routes have yet to be defined. Volumes are particularly significant in Belgium, where the radium-bearing waste currently stored on the Olen site comes from processing half of the radium sources used worldwide. In Spain, graphite waste from the gas-cooled reactors is currently being stored on a reactor decommissioning site. Nor is there any formal plan in Switzerland, the United Kingdom, Japan, the United States, Russia and Ukraine, which all possess graphite type waste.

Management of HLW waste

Most countries are moving towards deep geological disposal, but they are all at widely differing stages in the site selection and facility construction process.

Finland and Sweden have already selected their (first) sites, in Olkiluoto and Osthammar (location of the Forsmark NPP) respectively. Sweden is entering the construction authorisation application phase, while Finland received this authorisation in November 2015. The commissioning of these centres is scheduled for between 2020 and 2025.

In Finland, excavation of the Onkalo underground laboratory to characterise a granite environment for construction of the repository reached the reference depth of 420 m in the summer of 2010. Several in-situ tests are underway in Onkalo in order to examine various local characteristics of the rock mass. They include studies of the hydrological properties, retention, the mechanical behaviour of the rock and geochemical transformations. Testing of a confinement materials manufacturing pilot and of installation in Onkalo has started.

In Sweden, the site was selected in June 2009, following several years of detailed studies and investigations and a large-scale experimentation programme in the Aspö laboratory (near the Oskarshamn site which was not selected). The building permit application for a geological disposal facility for spent fuels was submitted in March 2011. If authorised, the fuels disposal facility will be built at a depth of about 500 m, in granite rock. Its construction should continue until the early 2020s.

In the United States, after choosing the Yucca Mountain site in 2002, the US-DOE (OCRWM) submitted a disposal facility building permit application in June 2008. The file was considered to be satisfactory and its examination was accepted by the safety regulatory body (NRC). However, the Obama administration decided that “Yucca Mountain was not a feasible option for the long-term disposal of spent fuels”. Since 2009, the repository preparation phase has received no further funding. Examination of the creation authorisation application, which had been suspended for a certain time, was finally completed in January 2015: the application file will need to be added to (in particular concerning the impact assessment) and as things currently stand, construction of the facility is not authorised. Additional credits will also be required to enable the NRC to make further progress with its investigation work. Modifications to the spent fuel and waste inventory or management policy since the authorisation application was submitted in 2008 could also affect future decisions concerning Yucca Mountain.

The "Blue Ribbon" commission, created in January 2010 to examine all the possible strategic options concerning the management of spent fuels and high-level radioactive waste, submitted its final report in January 2012. It reaffirms the fact that the reference solution must be geological disposal, in particular recommends the creation of an organisation in charge of radioactive waste disposal and recommends the storage of SF and a siting process based on acceptance. The reports takes account of the opinions and remarks of the public, obtained during meetings held in October 2011. Pursuant to the Blue Ribbon Commission's recommendations, the DOE notified its spent fuel management strategy in January 2013. It provided for a pilot storage facility that could be in service as of 2021, followed by storage of at least 20,000 tons (U metal) in 2025, situated either on the pilot site, or on the candidate site for the geological repository. Two projects to submit building permit applications to the NRC are therefore planned for 2016:

- the Waste Control Specialists company (in association with Areva) will in April 2016 submit a building permit application for a dry, centralised surface storage facility in Texas (Andrews County) near the Mexican border, with the aim of completing construction by December 2020.
- The Holtec company will in June 2016 submit a building permit application for a dry, centralised surface storage facility in New Mexico, and hopes to obtain the green light in January 2019, with the aim of starting operations in early 2020.

The commissioning of a future geological repository for spent fuels was announced for 2048.

Although the site has not yet been chosen, various milestones for the near or more distant future have been set in certain countries. Japan has initiated a vitrified waste disposal site selection process, with commissioning planned for about 2035; the process has however been stalled at phase 1 since July 2007 owing to a lack of candidates; a new information campaign was started in 2009, followed by a series of public meetings in 2012, which led to the definition of a new call for candidates and support process by the public authorities. Germany and China have set targets for initial operation of the geological disposal centre beyond 2040. After the 2013 expiry of the moratorium concerning the Gorleben disposal facility, underground exploration work on the salt dome was resumed and then interrupted in July 2013 by the *Repository Site Selection Act*. This Act, adopted by the Bundestag, requires the search for and selection of a disposal site, in any type of medium (clay, salt and crystalline) for high level waste, guaranteeing the "highest possible safety" for a period of 1 million years. The siting process should be concluded in 2031. Consequently, the Gorleben mine is maintained at a minimum level of operational activity.

Other countries have chosen to focus on research into geological disposal and in particular to postpone the site selection process. For example, no date has been set in Belgium or Canada (in both countries a gradual process involving the stakeholders has been set up). In the United Kingdom, the Government published the *"Implementing Geological Disposal"* White Paper in 2014, defining the programme for construction of a geological disposal facility, to allow operation of this facility as of 2029 (instead of 2040 as initially planned). Similarly, the Netherlands have built a long-term (about a century) storage facility, during which time geological disposal is to be studied.

On 30th December 2011, Spain chose the site of Villar de Cañas for its future spent fuels and high level waste storage facility. It is situated in Cuenca province about 130 km south-east of Madrid. Parliament had approved the development of a storage programme in 2006 and the Government opened up the siting search to all municipalities.
The electricity utilities today store their spent fuels on the NPP sites and in a dry storage facility, on the site of the Trillo NPP.
This dry storage is designed for a period of sixty years. It will have a capacity of 13,000 m^3 of high level waste, corresponding to 6,700 tU of spent fuels (20,000 assemblies) and 2,600 m^3 of intermediate level, long-lived waste and 12 m^3 of vitrified waste (fuels from the Vandellos NPP).

The announced cost is 700 million euros. It will be part of a technology park enabling about 300 jobs to be created. The construction project began in April 2013 and should last about 5 years. The design was entrusted to Areva and the engineering to a group headed by Westinghouse.
The building permit application was submitted in January 2014. The creation authorisation on the Villar de Cañas site was issued in July 2015. However, a new regional government was elected in 2015. It extended the area of the environmental protection zone, thus blocking development of the storage project, which at the end of 2015 was awaiting new political decisions. Operation is scheduled for 2018.

Research to support geological disposal

In most countries, the reference solution for managing high-level waste and intermediate level, long-lived waste, is deep geological disposal. In the 2011 directive, the European Council reaffirmed this: *"deep geological disposal is currently the safest and most sustainable solution as the final step in the management of high level waste and spent fuel considered to be waste"*. The host rock chosen varies according to its confinement properties and the geological possibilities of the countries concerned.

However, no country has yet issued a formal authorisation for disposal of this waste, including spent fuels, except for the United States with regard to waste of military origin. Most countries are experiencing significant delays in the development of their disposal programmes, owing to attempts to identify sites on primarily scientific and technical bases, without sufficient local consultation. Those who learned the lessons of this failure and who have restarted the process from the beginning, with prior debate and consultation, are now the furthest advanced.

In certain cases, scientific and technical feasibility can today be considered as proven and those few countries which have reached the most advanced stage are now in the final site qualification and concepts and engineering optimisation phase.

The organisation of research

With regard to research programmes concerning radioactive waste for which there is currently no industrial route, the most common option is to entrust oversight to the organisation responsible for management, whether private or public: SKB in Sweden, POSIVA in Finland, ENRESA in Spain or ONDRAF in Belgium.

This configuration nonetheless implies specific technical support, similar to that which Andra received from research organisations such as CEA: POSIVA with VTT, NAGRA with PSI, ENRESA with CIEMAT, ONDRAF with CEN-SCK.

Nonetheless, for historical reasons, R&D may sometimes be run by another organisation, in association with the future waste management operator and other research organisations.

A typical case is that of Germany, where there is considerable involvement by GRS (a research organisation which reports to the waste manager BfS) and the BGR, a German public research institute specialising in earth sciences and natural resources, specifically for geological disposal of exothermic waste. DBE (German company for the construction and operation of waste disposal facilities) has an exclusive contract with BfS for the construction, operation and monitoring of disposal sites.

Another special case is that of Japan, although the situation has become simpler since the merging of the two public research organisations, JNC and JAERI, into JAEA. In addition to JAEA there is CRIEPI, financed by the electrical utilities and RWMC, financed by METI.

The underground laboratory – a possible precursor to the disposal project

For R&D into geological disposal (SF or HLW and ILW-LL waste), the various configurations of the waste management organisation in the various countries considered leads to considerable differences in the status of the underground research laboratory, whether in terms of ownership or objective (methodology[226] or qualification of the site and the host rock).

In Sweden, the Hard Rock Laboratory at Äspö is the property of SKB (methodology and qualification of the granite). Since 1995, it has been carrying out research on its KBS3 concept (vertical vaults and copper container) under three-yearly R&D programmes approved by the Government. Since 2000, proof of concept demonstrators have been operational. Their aim is to acquire expertise in the construction and operation of a deep geological repository, for which authorisation was requested in 2011 for the Forsmark site in Östhammar.

In Finland, POSIVA is excavating a qualification laboratory in the granite at Onkalo on the actual site of the future disposal facility. Excavation reached its nominal depth of 455 m in February 2012. The research covers subjects such as geological surveys, instrumented drilling, characterisation niches and mechanical studies of the crystalline massif.

In Belgium, the objective of the Hades research laboratory, situated at a depth of 230 m, is methodological and it is used for qualification of the Boom clay. It is now managed by an EIG of ONDRAF and CEN/SCK, the Belgian counterpart of CEA. This laboratory is demonstrating the possibility of building a geological repository consisting of a network of drifts, with limited disturbances within the host clay formation.

Switzerland, with two laboratories of widely differing status:

- GTS (GRIMSEL Test Site), a granite environment methodology laboratory made available to NAGRA using drifts belonging to the electrical utilities; current research concerns the instrumentation and monitoring of the structures. However the Spanish proof of concept demonstrator for spent fuel disposal in drifts, called FEBEX and set up by ENRESA in 1997, is still active.
- Mont Terri, an international consortium initiated in 1996 by NAGRA and Andra and now run by a Swiss federal authority. The laboratory's objectives are methodological. It enables Nagra to qualify the clay in Opalinus (potential host rock).

At Mont Terri, about a hundred experiments have been carried out on different scales since the beginning of the research programme in 1996 and more than about sixty are still on-going in 2015. In a clayey material that had hitherto been little studied, rock characterisation methods were established. Thus, with regard to safety, the diffusion of radionuclides in clay was measured and the water contained in the rock was collected. Andra's close involvement in the Mont Terri projects

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[226] In other words a laboratory, the purpose of which is to develop "in situ" characterisation techniques, but which, owing to its status and geological environment, is not situated in a potential geological siting location.

and experiments enabled it to prepare for the experiments in the Meuse/Haute-Marne underground laboratory.

In Japan, JAEA is building two underground laboratories, with purely methodological objectives. In the Mizunami laboratory (crystalline rock), a depth of 500 m, out of the planned 1,000 m, was reached in 2015. Studies concerning hydrology and rock mechanics are on-going. In the Horonobe laboratory (sedimentary rock), hydrological tests and hydrochemical measurements are continuing. A depth of 350 m, out of the planned 500 m, was reached in 2015.

In Germany, following the experiments which took place in the 1990s in the former salt mine at Asse (for which the initial work dates back to the early 1970s). The Gorleben salt dome intended for disposal of high level radioactive waste was the site of extensive survey work until 2013. Under the 2013 Act requiring the search for a new site (in any type of geological formation), the survey work on the Gorleben site has been scaled down to the strict minimum.

In the United States, after about twenty years of research and characterisation work performed on the Yucca Mountain site in the State of Nevada, the DOE in June 2008 submitted an authorisation application for disposal of spent fuels in volcanic rock at Yucca Mountain. As mentioned earlier, this approach was politically called into question by the State, which undertook to redefine the disposal strategy for radioactive waste and spent fuels.

Coordinated research in Europe

Technological research and development work developed under the EU's R&D Framework Programme (FP) focuses on:

- the management and safety of geological disposal of High and Intermediate Level, Long lived waste (HLW/ILW-LL);
- the European dimension of its management and disposal;
- the development of processes enabling their quantity and harmfulness to be reduced (e.g.: partitioning, transmutation, etc.).

Projects in progress

Horizon 2020, the new European R&D and innovation framework programme started on 1st January 2014 for a period of 7 years. It finances truly interdisciplinary projects around three priorities:

- scientific excellence,
- industrial leadership,
- the challenges of society.

Horizon 2020 has an allocation of 79 billion euros (current euro value, including Euratom) to support scientific and industrial work in the European Union for the period 2014-2020.

The Euratom programme is an integral part of Horizon 2020 and is subject to the same regulations, covering:

- the R&D programme on the subject of fusion,
- research in the field of fission and radiation protection,
- the nuclear activities of the Joint Research Centre (JRC).

The various projects and research programmes in progress within the framework of Euratom, the scope of which concerns developments in radioactive waste management, are as follows:

- MODERN 2020: Development and implementation of repository monitoring and surveillance techniques – (Coordinator Andra);
- IGDTP-2: Technological Platform aiming to coordinate resources and actions in the field of geological disposal facility projects (Andra);
- JOPRAD: European joint research programme project on radioactive waste disposal;
- DOPAS: Full scale demonstration of the construction and performance of seal structures;
- MIND: Influence of microbial processes on geological waste disposal;
- Cebama: Cement-based materials for geological disposal;
- FIRST Nuclides: Acquisition of data on the IRF (labile fraction of the source term) for high burnup fraction UOx fuels, in particular to reduce the uncertainties associated with certain radionuclides of interest (^{123}I, ^{79}Se, ^{135}Cs, ^{14}C) – (KIT);
- LUCOEX: Experiments in 3 underground laboratories to test and confirm the conceptual choices made (SKB).
- SKIN: Very slow kinetic process in fluid-rock interactions (EM Nantes)

IGD-TP - Implementing Geological Disposal of Radioactive Waste Technology Platform

The aim of the IGD-TP technological platform, created in 2009, is to promote R&D contributing to the commissioning of the first geological repositories for spent fuels, high level waste and other long-lived radioactive waste.

The discussion forums of this platform, in which 23 countries of the European Union are participants, along with Switzerland, counted some 120 participants as at the end of 2014. They come mainly from European organisations, but also from Japan and other countries. These organisations are bodies in charge of waste management, Government institutions, companies, universities and research centres.

The role of IGD-TP is to boost confidence in the safety and implementation of radioactive waste disposal solutions in deep geological formations. The IGD-TP not only allows the development of technical programmes of interest for the most advanced countries, but also enables the States to benefit from the most recent progress, as of the initial stages of their development. Most of the nuclearized countries have developed radioactive waste management programmes, but their progress, their implementation schedules and the issues involved are different.

The commitment by the platform members is to:

- reinforce the confidence of European citizens and decision-makers in the safety of geological disposal solutions,
- encourage the drafting of waste management programmes which include geological disposal as an accepted option for the long-term, safe management of high level waste,
- facilitate access to expertise and technology and maintain skills in the field of geological disposal, to the benefit of the Member States.

In 2011, the IGD-TP produced a strategic research programme[227] and a 2011-2016 deployment plan[228]. For the European Community, these two documents are a means of bringing together the highest level of skills around major research objectives for the next fifteen years and of organising cooperation on topics of common interest at a European level.

In 2014, an updated version of the deployment plan was published (*Master Deployment Plan 2014*[229]). Implementation of this research benefits from funding included in the 7th Framework Programme for technological R&D, which has today been superseded by the "Horizon 2020" programme.

The research programmes concern safety studies, waste and how it behaves, performance and feasibility of repository components, development, construction and operation of a repository, monitoring and surveillance, governance and stakeholder involvement.

In 2014, the activities of the IGD-TP were covered by 8 technical projects:

- Three projects were completed in 2014:
  - MoDeRn: *Monitoring developments for safe Repository operation and staged closure*,
  - PEBS: *Long-term Performance of the Engineered Barrier System*,
  - REDUPP: *Reducing the uncertainties in the spent nuclear fuel dissolution rates used when assessing the long-term safety of geological disposal concepts of nuclear waste*.
- Five projects are continuing beyond 2014:
  - BELBaR: *Bentonite Erosion, effects on the Long term performance of the engineered Barrier and Radionuclide transport*,
  - CAST: *Carbon 14 Source Term*,
  - DOPAS: *Demonstration Of Plugs And Seals*,
  - First-Nuclides: *Fast / Instant Release of Safety Relevant Radionuclides from Spent Nuclear Fuel*,
  - LUCOEX: *Large Underground COncept EXperiments.*

To this must be added a "support action", the IGD-TP secretariat: the SecIGD2 project.

<u>Horizon 2020 call for projects "work programme 2014-2015" (H2020 WP 2014-2015)</u>

The IGD-TP[230] is involved in four project proposals accepted under the Euratom H2020 WP 2014-2015 call for projects and which will start in 2015:

- a project on concretes called Cebama - *Cement-based materials, properties, evolution, barrier functions*,
- a project on the influence of micro-organisms in disposal processes, called MIND - *Influence of microbial processes on geological disposal of radioactive waste*,
- a project on monitoring, called Modern2020 - *Development & Demonstration of monitoring strategies and technologies for geological disposal*, following on from the Modern project,
- a coordination project (Coordination and Support Action): called JOPRAD - *Towards a Joint Programming on Geological Disposal* – which aims to assess the methods for coordinating European research work (*Joint Programming*) in the field of geological disposal.

Andra acts as Coordinator for the Modern2020 and JOPRAD projects.

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[227] This document is available on the Andra website: https://www.andra.fr/download/site-principal/document/igtdp_strategic-research-agenda.pdf

[228] This document is available on the Andra website: https://www.andra.fr/download/site-principal/document/igdtp_deployment_plan_2011-2016.pdf

[229] This document is available on the Andra website: https://www.andra.fr/download/site-principal/document/igdtp_master-deployment-plan-2013.pdf

[230] Additional information is available on the site: http://www.igdtp.eu/.

SITEX – Sustainable network of Independent Technical EXpertise for radioactive waste Disposal

The SITEX project (*Sustainable network of Independent Technical EXpertise for radioactive waste Disposal)* was carried out from 1st January 2012 to 31st December 2013 under the European atomic energy community's (Euratom) seventh framework programme for nuclear research and training. Its aim was to identify the conditions and means necessary for creating an international network of public expertise to address the safety and radiological protection questions posed by the geological disposal of radioactive waste. This work led to the identification of priority topics in terms of R&D, development or harmonisation of technical guides.

A follow-up to this project was launched in June 2015 for a period of 30 months, under the European Commission's Horizon 2020 programme, which aims primarily to set up a platform for exchanges by independent technical experts for studies into geological disposal facilities.

OECD-NEA

The role of the Nuclear Energy Agency (NEA) is not to run research programmes but rather to bring together players from the various countries to deal with subjects that need to be shared between countries.

The Radioactive Waste Management Committee (RWMC) assists the member countries with management of radioactive substances and waste, more specifically with regard to developing strategies to guarantee the safe, sustainable and generally acceptable management of all types of radioactive waste, in particular long-lived waste and spent fuel, along with the decommissioning of end-of-life nuclear facilities.

The RWMC's main tasks are:

- to create a forum for the exchange of information and experience on waste management policies and practices in the NEA member countries;
- to develop a common understanding of the fundamental questions involved and to promote the adoption of common philosophies based on the various possible waste management strategies and their alternatives;
- to monitor changes in the technical and scientific state of the art in the management of radioactive materials and waste;
- to contribute to the dissemination of information in this field through the organisation of meetings of specialists and the publication of technical reports and joint opinions summarising the results of joint activities on behalf of the international scientific community, the competent national authorities and other audiences interested by the topic;
- to provide a framework for on-demand performance of an international peer review of the activities of a country in the field of radioactive waste management, such as R&D programmes, safety assessments, specific regulations, etc.

Incidents at the Waste Isolation Pilot Plant – WIPP in the United States

The first disposal facility for long-lived radioactive waste in a geological formation (salt dome type), the WIPP, was commissioned in 1999 in New Mexico. Its operation was however interrupted in February 2014 as a result of 2 events which occurred 10 days apart:

- 5th February: an underground fire on a transporter engine led to many operators being evacuated owing to intoxication by smoke inhalation.
  Source: US DoE

- 14th February: radioactive contamination detected on the surface of the site near the air extractor, albeit at levels presenting no risk for the public or the environment. This contamination was the result of an exothermic reaction due to chemical incompatibility between an organic absorbent material introduced into a drum and its content, a radioactive nitrate salt.
  Source: US DoE

The disposal of transuranic waste, of military origin, should gradually resume as of 2016 after an interruption of two years. Using an incremental approach, the restart is described in the "*WIPP recovery plan*", published by the DOE at the end of September 2014. With a capacity of about 175,000 m^3, the WIPP houses radioactive waste in chambers excavated from a salt formation at a depth of about 650 metres.

These waste are produced by American defence activities as a result of operation, decommissioning and post-operational clean-out of facilities which used or produced transuranic elements, that is with a radioactive half-life longer than that of uranium.

The restart programme involves seven key aspects: safety, regulatory conformity, remediation, ventilation, mine stability and habitability, personnel training and the resumption of waste disposal.

The second phase will consist of a series of steps designed to remediate the contamination source, restore the conditions necessary for operation and learn all necessary lessons from the two incidents in February, in the form of programmes and procedures, before operations resume.

Appendix 4: Research for the period 2016-2018

This PNGMDR appendix aims to present a summary of research carried out on the management of radioactive materials and waste during the period of the previous plan (2013-2015) and the medium-term research prospects.

This document is not however exhaustive in that certain long-term future subjects can be carried out in parallel.

After presenting the key players in the research carried out under the PNGMDR, it is built around the following strategic objectives:

- Improving knowledge and working upstream on waste packaging and the behaviour of the packages;
- Supporting disposal projects for HLW, ILW-LL, LLW-LL type waste and storage projects;
- Continuing research on generation IV fast neutron reactors and the possibility of setting up a closed fuel cycle.

The last section of this appendix presents the main research facilities used for the studies carried out under the PNGMDR.

Key players in research carried out under the PNGMDR

Research in the sustainable management of radioactive materials and waste is primarily the responsibility of two organisations: the National Agency for Radioactive Waste Management (Andra) and the Alternative Energies and Atomic Energy Commission (CEA) whose respective responsibilities in this field were originally set by Act 91-1381 of 30th December 1991 concerning the long-term management of radioactive waste.

The main results of the research carried out within the framework of this Act were summarised in 2005, enabling the broad outlines of the Programme Act of 28th June 2006 on the sustainable management of radioactive materials and waste to be defined.

Three additional research priorities are defined for long-lived high level or intermediate level waste:

- Priority 1 (overseen by CEA): search for solutions allowing the partitioning and transmutation of long-lived radioactive elements present in these waste;
- Priority 2 (overseen by Andra): studies aiming to be able to commission a reversible deep geological disposal facility;
- Priority 3 (overseen by Andra): studies to meet the need for storage capacity identified by the PNGMDR.

R&D actions are also performed by industry (EDF and Areva), partly under agreements linking them to CEA or Andra. As necessary, all of these organisms draw on the pool of expertise available at the CNRS, which restructured its research in 2011 around a new cross-cutting research programme called “Nuclear: energy, environment, waste, society” (NEEDS) and in the Universities and other organisations, such as the BRGM or INERIS. Finally, one must mention IRSN, where research aims primarily to acquire a satisfactory level of nuclear safety and radiation protection expertise enabling it to play in full its role of technical support for ASN and ASND.

The national plan for radioactive materials and waste management, which has been in place since 2006, describes the management solutions developed for radioactive materials and waste and specifies a certain number of research strategy milestones over a period of three years. The National Review Board (CNE2) regularly assesses the research carried out in this field and in its recommendations proposes a number of orientations for the strategy to be implemented. It should be noted that the Board is in favour of a European and international focus for the research performed by Andra, CEA and the CNRS[231].

We must underline the European Commission's desire to build synergy between the various players in the management of radioactive materials and waste, through the launch of the JOPRAD project in 2015, involving three types of players: the organisations in charge of geological disposal (Waste management operators, WMO, i.e. Andra for France) already grouped together in the European IGDTP platform (Implementing Geological Disposal of radioactive waste Technology Platform), the scientific organisations providing expert support for the safety regulators (Technical Safety Organisations, TSO, i. e. IRSN for France) which are already in contact through the European SITEX and SITEX II projects, and Research Entities (RE) such as CNRS, CEA, BRGM, etc. some of which are already partners in a joint programme (PF) within the framework of NEEDS, for geological disposal.

To ensure the implementation of a common strategy by all the operators involved in all these research programmes and to monitor the activities via the various cooperative agreements reached internationally, two committees were set up, jointly chaired by the DGEC and the DGRI:

- COSRAC (Committee for the Monitoring of Research on the Cycle Back-End) set up in 1995,
- COSSYN (Research orientation and monitoring committee for nuclear systems), set up in 2007.

Merging of these two committees is currently being envisaged, as part of the energy transition process, to give the supervisory bodies the best possible vision of the various conceivable scenarios for the future of the nuclear power plants (safety and lifetime of existing reactors, deployment of 3rd and 4th generation reactors, including fast neutron reactors) and the implications in terms of R&D requirements for reactor and cycle physics, whether dealing with questions concerning the management of materials (multi-recycling of plutonium, recycling of depleted uranium, development of a new generation of fuels and cladding materials, etc.) or waste (nature of waste produced, R&D to develop new processing-packaging processes, impact of management modes on the inventory of HLW, ILW-LL, LLW-LL waste, tritium, waste currently "with no disposal route" and the design of the facilities intended for management of these waste).

Improving knowledge and working upstream on waste packaging and the behaviour of the packages

The licensee of a radioactive waste packaging facility, together with the producer of the waste, is responsible for the quality of the radioactive waste package produced. It must manage its characteristics and, to do this, must produce a file defining the packaging methods and specifying the behaviour of the package produced, more particularly in disposal conditions. Andra will eventually produce the specifications for acceptance in its facility for disposal. The producers of

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[231] Evaluation report n°9 is available on the CNE2 website: www.cne2.fr

radioactive waste packages shall demonstrate the compatibility of the packages produced with these specifications.

At the request of the producers and the licensees, CEA performs a significant share of the R&D necessary for implementation of the processes and for improving the understanding of the characteristics of the packaged waste.

To establish these acceptance specifications, Andra has set up long-term behavioural study programmes for the various package families in the disposal environment. In order to carry out this R&D, Andra realised that it was necessary to set up dedicated structures taking the form of laboratory groups. CEA and EDF take part in some of these laboratory groups.

All the players agree that it is essential to continue the following avenues of research, according to the additional and targeted needs in the repository nuclear safety cases:

- improve the modelling of the behaviour of waste packages in disposal conditions, to reduce uncertainties when justified by the impact assessments,
- on a case by case basis, specify the radiological inventories which could by default be over-evaluated, by developing or improving analytical means or by deploying appropriate statistical ratio calculation techniques for the more easily measurable radionuclides;
- as necessary, specify the chemical inventories and the source terms of the chemical and gaseous compounds important for safety in the repository operations phase;
- specify the release kinetics for waste for which the source terms are currently considered to be too conservative or penalising (labile).

The improved understanding of the packages obtained through this research should in the end make it possible to verify the acceptability of the packages for disposal, in accordance with the criteria defined for each type of repository.

Graphite waste: management and processing scenarios

One of the solutions envisaged for graphite waste management is based on the direct disposal of all graphite waste in a near-surface repository.

However, since 2009 EDF, together with CEA and Andra, has been carrying out an R&D programme concerning a graphite waste decontamination process using thermochemical treatment.

Depending on the resulting decontamination performance, this process could be used:

- either in a scenario taking treatment as far as gasification of the graphite once sufficiently decontaminated,
- or in a scenario implementing a decontamination step prior to disposal.

The results obtained showed that gasification, which involves a highly complex prior decontamination step, is no longer an industrially realistic hypothesis. Treatment is however still of interest in that it guarantees the acceptability of the graphite waste for disposal, with a satisfactory level of safety.

In this context, ongoing and planned R&D actions concern:

- the continuation of work to identify the duration of treatment and the optimum temperature/treatment gas composition combinations,
- the progress of the reactions following treatment and the selectivity of the treatment process,
- quantification of the influence of treatment on the speciation and release of radionuclides,
- identification of potential management routes for waste resulting from the treatment process.

ILW-LL waste

Bituminised sludges

Between 2013 and 2015, Andra, AREVA, CEA and EDF carried out a joint R&D programme on the behaviour of bituminised sludge packages, in response to a request from the National Review Board for research and studies on the management of radioactive materials and waste (CNE2) whose report n°6 at the end of 2012 stipulated that it wishes: *"owing to uncertainties in the behaviour of bituminised sludge packages, in particular in the event of a fire (…) to receive a full-scale demonstration by December 2014, with a safety analysis of the behaviour of the primary package and its container in the repository, in the most penalising conditions"*. The CNE2 asked that *"the safety analysis be carried out jointly by CEA and Andra"*. The study programme thus focused on providing the results of the demonstration that the fire risk was controlled during the operations phase of a deep geological disposal facility.

This joint programme covers the following avenues:

- the study of the intrinsic thermal behaviour of bituminised waste, from the small laboratory scale up to full-scale, reproducing the effects of a fire in actual conditions on a concrete disposal package containing 4 primary encapsulated packages representative of industrial bituminised waste;
- the experimental study and modelling of radiolysis of bituminised waste, aiming to quantify the hydrogen source term and the potential impact on the mechanical strength of the concrete disposal package;
- the acquisition of additional experimental data on the swelling resulting from the uptake of water by the salts contained in the bituminised waste in order to confirm the absence of prejudicial interactions between the bituminised waste and the mechanical properties of the Callovo-Oxfordian around the vaults.

The results of this R&D programme were considered to be positive by Andra, Areva, CEA and EDF. The last report from the CNE2 considers that: "The studies on the resistance of bitumen packages in disposal in the thermal conditions of a major fire demonstrate the robustness of the disposal packages and the chemical inertia of the bituminised waste. These new data dispel the fears related to fires originating outside the packages in the Cigeo installations.[232]

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[232] CNE2 evaluation report n°9, June 2015, p. 7.

ASN will however be carrying out an in-depth examination of these results in order more specifically to rule on the possibility of disposing of bituminised waste packages in the first tranche of the deep repository.

Technological waste containing organic matter rich in alpha emitters

Technological waste rich in alpha emitters comes from fuel fabrication and processing facilities. The particularity of this waste is that it contains both metal and organic matter. In the disposal situation, the radiolysis process in the organic matter producing hydrogen gas is therefore studied. The radiolysis then subsequent hydrolysis by future resaturation of the disposal vaults will produce organic molecules that are potentially complexing for certain of the actinides such as uranium and plutonium. Several study approaches are possible for evaluating the long-term consequences on the potential migration through the geological barrier of radionuclides complexed in this way by such processes. Andra thus opts for an upstream approach aiming to complete the thermodynamic bases of the main expected complexes in order to verify their stability domain in geological conditions.

In the field of radiolysis, R&D work has been performed by CEA and Areva and led to the development of a database and predictive models designed to quantify the gas source terms of these packages. With regard to determining water-soluble degradation products (PDH), the work already under way will continue in the form of a joint Andra/producers R&D programme. The aim of this programme is to obtain data to quantify the conservative nature of the assessment of these PDH and their complexing capacity.

At present, CEA packages this type of waste using compaction and cement encapsulation. Areva has a cement encapsulation packaging mode for some of the alpha contaminated technological waste. Not all of the waste produced can be packaged in this way and Areva has carried out studies to develop thermal processes.

The orientation studies concerning the thermal processes performed in 2010/2011 revealed the absence of any technology that could be directly transposed to technological waste containing organic matter rich in alpha emitters. Since then, R&D has concentrated on incineration/melting/vitrification technologies involving plasmas, which most closely match the process specifications. They consist in heating the metal phase by low-frequency induction and then heating the glass by heat transfer at the metal/glass interface. One or more plasma torches are sufficient to ensure combustion of the organic part of the waste.

These technologies are based on major technological innovations (use of a plasma torch in a nuclear environment, deployment of fusion and vitrification operations within the same process, final packaging comprising two separate glass/metal phases in the same container, etc.) and feasibility has yet to be confirmed. They generally imply the ability to manage specific criticality constraints and the use of a very high temperature process associated with a glove box design.

At this stage, the production of a full-scale prototype was felt to be necessary and this was the subject of R&D over the period from 2011 to 2018. It should allow inactive qualification of the process. Funding for this R&D has been requested under the investing in the future programme.

Other ILW-LL waste

In the 2005 File concerning the feasibility of geological disposal in a clay layer, the models and data available for ILW-LL waste mainly concerned the corrosion rates of the metal materials in standard compacted waste packages (CSD-C) and the source terms of bituminised sludge packages. The studies carried out since then by CEA, Areva and EDF, to meet Andra's need for data, confirm these elements, but also provide initial additional information concerning the following waste:

- metal waste: determination of corrosion rates of aluminium and magnesium alloys;
- polymer waste: evaluation of radiolytic production rates for different gases and different polymers, determination of the nature and quantity of water-soluble degradation products resulting from the radiolysis and hydrolysis of these polymers;
- ILW-LL glasses: proposal of a glass alteration model.

Spent fuels

A study programme for PWR fuels was carried out at the request of the PNGMDR, which was to produce a less conservative release model than that adopted for the 2005 File, by 2011. The work done on this project can to a large extent be transposed to other fuels[233] with a UO_2 matrix.

A spent fuels matrix alteration model was developed by CEA. It includes radiolysis, geochemistry and electrochemistry. It is applicable to UOx and MOx fuels and should eventually allow coupling with the materials in the environment. It leads to a fuel lifetime similar to that adopted in the 2005 File (from 50,000 to 100,000 years).

Initial experimental results on the dissolution of UO_2 doped with clayey water would also seem to show control of alteration by a silicate phase (uranium silicate). This could lead to a slower alteration mechanism than that shown by current models for certain radionuclides.

In the rest of these actions, it will be necessary to include the results obtained by the FIRST-Nuclides programme, conducted at a European level and to continue with the experimental and modelling work on the behaviour of UOx and MOx fuels, in order to clarify the available data, more specifically with regard to their respective behaviours in disposal conditions.

Vitrified waste

The initial and residual dissolution rates of the glasses (R7/T7) produced at La Hague were assessed throughout a broad range of environmental conditions: atmospheric corrosion, alteration in pure or clayey water, alteration in the presence of environmental materials (corrosion products and argilites):

- the atmospheric corrosion of glass (in the presence of water vapour) leads to alteration rates higher than the residual rate in pure water;
- the glass dissolution rates in pure and clayey water were acquired at 30°C, leading to a reduction in glass alteration by comparison with the 50°C values adopted in the 2005 File;
- glass corrosion in clayey water leads to initial rates 5 times higher than those obtained in pure water. The residual rates are also multiplied by a factor of 1 to 5 depending on the magnesium concentration in the vicinity of the glass and the pH.

The corrosion products from the metal sleeves and over-packs are the result of a long-term process (several thousands to tens of thousands of years) and consist mainly of iron carbonate. These corrosion products increase the alteration kinetics of the glass and delay the residual rate transition

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[233] Spent fuels from civil reactors (GCR and EL4 heavy-water reactor, experimental CEA reactors, land or ship-borne reactors operated for national defence-related activities.

owing to their ability to sorb and co-precipitate the silica. Moreover, the studies carried out on the compression behaviour of the glass confirms very little evolution in its fracturing under mechanical load in the repository. This mechanism would not therefore be liable to degrade the long-term confinement provided by the vitreous matrix.

At the same time, a mechanistic model of the long-term behaviour of the R7/T7 glass, the GRAAL model, is currently under development. This model aims to describe the complete kinetics of glass dissolution as a function of environmental conditions. The current studies aim to expand its scope of application so that this mechanistic description can be integrated into the operational model of vitrified waste package behaviour in a disposal situation.

Two alteration models are adopted for HLW glasses. The first is based on the initial alteration rate and is carried out for lifetimes of a few hundred to several thousand years. The second is based on the residual rate and leads to lifetimes of several hundred thousand years. The first model applies to most of the "cold"[4] glass (UMo, PIVER and AVM glasses) while the second applies to "hot" glasses and to a few families of AVM glass.

With regard to the performance and safety calculations needed for the Cigeo creation authorisation application, this work will allow a more precise and robust evaluation of the behaviour of these glass families in a disposal situation. The work to be done in the coming three years should in particular concern:

- alteration of the glass in "unsaturated" conditions (presence of water vapour), in order to cover the first post-closure phase of the geological repository;
- alteration in the water on the site and identification of the effect of magnesium;
- the influence of environmental materials, more specifically of corrosion products;
- interpretation of the results of the underground laboratory experiments.

Generation IV fast neutron reactor waste

The aim is to obtain the data necessary to prepare for gradual deployment of generation IV fast neutron reactors:

- initially supplied with the uranium and plutonium contained in the fuels taken from PWR reactors (more specifically spent MOx fuels);
- then with the implementation of systematic recycling of the uranium and plutonium;
- and, as necessary, the use of transmutation options for certain minor actinides.

It will be necessary to examine the impact of these developments in technology and material management strategy on the waste generated. The remote deployment time-frame for these systems enables innovative R&D to be carried out on these subjects. The following primary research objectives can be mentioned:

- studies to limit the generation of waste comprising long-lived elements, as of the design stage;
- the study of alternative treatment and packaging solutions, for example a melting process for metal waste;
- the characterisation and management of waste, in particular secondary waste (cladding, structural elements of fuel assemblies) and reactor operating waste (cold traps, control rods);
- the impact of transmutation options on the design of the disposal facility (for example to assess the impact of a glass thermal load that is significantly reduced over the long term).

Supporting disposal projects (HLW and ILW-LL, LLW-LL waste) and storage projects

Disposal of low level, long-lived waste

The deployment of long-term management routes for LLW-LL type waste has been based on R&D for at least the past 10 years, in order to clarify the feasibility, acquire the additional data necessary to demonstrate the safety of disposal and draft design requirements for the industrial means that are eventually to be selected. These means concern near-surface disposal and the upstream operations such as possible treatment and packaging of the associated residues. The R&D concerning these operations is specified in section 2.1 of this appendix.

In 2015, Andra submitted an interim report, presenting the conclusions from the geological investigations carried out over the period 2013-2015 and the progress made in the waste studies and research carried out by Andra and the producers (EDF, CEA, Areva, Solvay). Preliminary design studies for the repository were carried out and Andra performed an initial safety assessment of them. At the same time, analysis of the various LLW-LL graphite and bituminised waste management scenarios was continued within the PNGMDR working group on management route optimisation. On this basis, the report identifies the subjects requiring further examination in the follow-up study and research programme for the site being investigated and for the inventory of LLW-LL waste, in order to provide safety case data for creation of the repository.

Andra's studies led to the definition of a zone of about 10 km^2 to the north of the study sector, whose geological characteristics it felt were favourable for continued study of a near-surface repository (average thickness of the clay layer about 55 m and slight descending hydraulic gradient). The additional geological investigations to be performed in this zone in 2016-2017 will aim to clarify the available data on the geological environment.

The main key points for the next steps in the R&D programme are as follows:

- continued geological investigations in the favourable 10 km^2 zone in order to obtain more detailed data (surface deposits, chemistry of tile clay waters, in particular on the surface, organisation of flows and run-offs, etc.);
- continued work to characterise the waste (radiological and chemical inventory, speciation of carbon 14 in the graphite waste, in particular the quantity and molecules of the organic form, etc.);
- study of radionuclide behaviour in disposal conditions (conditions of release by the waste and retention in the cement-based and clay-based materials, in particular the organic ^{14}C molecules, etc.);
- study of the hydromechanical and geochemical behaviour of the reworked cover in the case of a repository with open excavation.

Reversible disposal in deep geological layer for high level and intermediate level long-lived waste - Cigeo project

Progress of the Meuse-Haute-Marne experimental underground laboratory programme

Andra has made a major effort in terms of testing in the underground laboratory and on the surface, concerning HLW vaults and seals.

HLW vault

In 2014, tests continued on the construction of high-level waste (HLW) disposal vaults, with excavation in the underground laboratory. The vault concept has changed: in a vault 40 metres long, cement grout filling of the space between the excavated rock and the metal liner of the vault was tested. The aim is to manage the acid transient linked to oxidation of the near field argilites at excavation and eventually to avoid the high corrosion kinetics by encouraging the formation of a passivation layer. The study of liner deformation is in progress. Additional tests are planned for the end of 2015 and in 2016 on vaults 80 metres long, using industrial space filling methods.

Excavation

The design of the repository must preserve the favourable properties of the rock. To do this, the impacts of excavation of the rock and of the input of materials and substances from outside the medium must be minimised. A new two-stage excavation method was tested in the Underground Laboratory in 2014: "deconfinement prior to excavation" (DPC). This involves excavating an initial small-diameter drift to create an initial mechanical unloading and then to broaden the drift, taking advantage of the initial unloading to eventually minimise the damage. The diameter of a drift 43 metres long was thus increased from 3.5 to 5 metres between July and October 2014.

Seals

Andra must demonstrate its ability to close the repository in order to prepare the Cigeo creation authorisation application. To do this, a number of additional experiments aimed at providing an overall view of the construction process and then the behaviour of the sealing of a structure in the Callovo-Oxfordian layer were carried out in 2014 or reached an important milestone at the end of 2014.

The ground support in the underground laboratory drift at a depth of 445 metres was removed. This support removal is envisaged in Cigeo in order to ensure direct contact between the clay rock and the swelling clay core in the seals of the shafts and ramps connecting the surface and the bottom installations. Over a length of 6 metres, the metal arches forming the ground support were removed. The technical feasibility of the operation was demonstrated. The observations and measurements made show that the ground is stable and that the wall deformations are at this stage negligible. Long-term monitoring of the structure and of the permeability of the surrounding rock has been put into place.

As part of the FSS (Full Scale Seal) experiment included in the European Dopas project, Andra has built a representative mock-up of a section of a Cigeo drift in a warehouse in Saint-Dizier. In 2014, this 10m diameter mock-up drift was sealed. Two different techniques were tested to create the support blocks able to contain the bentonite core when it swells: one of the supports was made with a self-positioning fluid concrete, while the other uses the industrial sprayed concrete method. For the 750 m^3 bentonite core, a mixture of bentonite powder and pellets was used, with filling by means of conveyor tubes. The first qualitative analysis of core filling and of the support walls, shows that the operations were satisfactory. At the end of 2015, the seal is scheduled to be dismantled, which will enable a dismantling methodology to be implemented, for possible use in any operations to retrieve packages from ILW-LL waste vaults.

Although the purpose of the FSS test is to develop and validate an industrial method for building a seal, a full-scale study of the complete bentonite hydration and swelling process cannot be carried out: at least several thousand years would be needed to totally resaturate the 750 m^3 of bentonite in the FSS. To study this process, work on a smaller scale is needed. This is being done through the Metric Scale Resaturation (REM) test being carried out in the technological area of the Meuse/Haute-Marne facility. This involves a stainless steel tank which was filled in 2014 with 1 m^3 of FSS bentonite mixture, with the mixture then being hydrated. The system comprises hundreds of sensors for monitoring the kinetics of hydration up to total saturation of the core (estimated at some time within the next 30 to 60 years) and of the swelling pressure associated with hydration.

Between the full-scale FSS technology demonstrator and the REM test, Andra is carrying out the seal core experiment (NSC) on the hydromechanical behaviour and hydraulic performance of a seal core. This study is taking place in one of the underground laboratory drifts, about 5m in diameter, or half the size of the drifts envisaged for Cigeo. This seal test comprises two concrete walls and a core of compacted bentonite bricks. In 2014, artificial hydration of the core was started: total saturation is estimated at between 1 and 3 years, owing to the installation of numerous hydration devices at the heart of the bentonite core.

Finally, alongside these tests, the BHN (bentonite natural hydration) experiment was also started in 2014. This involves a seal built in the underground laboratory in a tunnel 70 cm in diameter and 3 m long, naturally hydrated by the rock alone.

Outlook for the Meuse-Haute-Marne experimental underground laboratory programme

The experimental programme until 2017 intends to further intensify the technological tests and experiments in order to address the needs of the organisations assessing the R&D programmes (CNE in particular) and acquire the data needed to draft the creation authorisation application in compliance with ASN's requirements. The work is being organised on three points:

- Continue the programme associated with the construction of drifts and HLW vaults;
- Complete acquisition of geomechanical data on the characteristics of the Callovo-Oxfordian argilites (behaviour laws for sound argillite and for damaged argillite, corresponding to a dense 3D network of interconnected fractures, THM behaviour of the argilites, water and gas flow properties in the damaged zone), with priority given to engineering and simulation study programmes;
- Continue testing of the drift sealing components, with a view to technological optimisation of the disposal structures, plus performance testing.

To carry out this programme, new drifts will be excavated between 2015 and 2017.

Contributions to phenomenological understanding of the disposal centre

Here we look at three topics on which, by means of experimentation and modelling, significant progress has been made in understanding the properties and behaviour of various components of the disposal centre, more specifically the geological medium.

The damaged zone in the argilites around the disposal structures

The initial damaged zone (defined as being that following excavation) is today characterised, starting from the structure walls, by two nested zones:

- a zone, referred to as connected fractured, corresponding to a dense 3D network of interconnected fractures;
- a zone, referred to as discrete fractured, characterised by fractures which are only slightly connected, if at all.

These two zones have an overall elliptical shape; the dimensions of the small axes of the connected fractured zone (EDZ) and the discrete fractured zone are virtually identical, whereas those of the large axes differ significantly (several radii). This structuring of the damaged zone is repeated whatever the size of the structure. Given the in-situ mechanical stress field, it is due to the weak anisotropic behaviour of the argilites on a path that is being formed. The deformation measurements show that most of the short and medium-term deferred behaviour is located in the damaged zone, more specifically at the fractures.

Andra considers that the experimental data obtained underline the self-sealing capability by swelling of smectite minerals and mechanical closure of the damaged argilites. These mechanisms intervene very rapidly and lead to the restoration of very low water permeability close to the low level of the argilites themselves.

Waste and Spent fuels

2014 was marked by the consolidation of knowledge on the behaviour of waste packages and by the production of radionuclide release models in preparation for a safety options file (DOS):

- With regard to vitrified waste, the initial experiments with site water alteration at 70°C enables the threshold pH to be determined (pH70° = 7.5 ±0.1) above which precipitation of the magnesium phases is observed, determining the glass alteration rate. Most of the R&D work concerned the interactions between the glass and the surrounding materials and more specifically the characterisation at this interface of the iron silicates, which are a key factor when determining the residual alteration rate of the glass in the repository. The 2015/2016 studies will include design modifications to the HLW vault and in particular any interactions between the cement-based filling material placed between the liner and the rock and the vitrified waste.
- Studies on the ILW-LL waste mainly concerned two aspects: radiolysis and hydrolysis of polymers, with significant progress in estimating the production of hydrogen gas and quantification of the complexing species released and the problems linked to the disposal of packages of bituminised sludges, for which considerable data was obtained, in particular on the fire risk, gas production and swelling by radiolysis. In addition, ILW-LL glass release models were produced on the basis of leaching tests in cement water; these tests show the presence of a resumption of glass alteration in the presence of “conventional” cement, but not in the presence of low pH cement. R&D results are expected by 2015/2016 on the following topics: swelling under water of bituminised sludges and the corrosion of aluminium alloys in a cement environment.
- R&D on spent fuels led mainly to the proposal of source terms for UOx and MOx fuels, based on the electrochemical alteration model developed by Andra, CEA and EDF. In addition, experimental work highlighted the low level of uranium releases in solution in disposal conditions, more particularly in the presence of iron.

Disposal materials

An important issue for materials R&D concerns the design and sizing of the containers and liners of the HLW waste vaults. The experiments in the underground laboratory showed that oxidation of the minerals (pyrites) in the argilites of the vault wall during excavation were the reason for a process of acidification of the medium in contact with the liner at resaturation; this process is liable to lead to high corrosion rates of several hundred micrometres per year. These results guided the design choices for the HLW vault towards the installation of a filling material (cement-based) between the liner and the rock, in order to create an acid-base buffer. The R&D work thus concerned the definition of a composition range for this material and its chemical evolution over time and more generally the geochemical conditions within the HLW vault. This entails ensuring both an acid-base buffer and limiting eventual interactions between this cement-based material and the vitrified waste; this is why a low pH cement is for the time-being preferred. Furthermore, given the expected anisotropic mechanical behaviour of the HLW liner, stress corrosion tests were performed on the steel used for the liner. They will be continued to include the steel of the container and the cement-based filling material.

With regard to the cement materials, coupled hydration/mechanical properties models (initially developed for the CEM I cements) were developed for mixed cements (blast furnace slag cements and fly ash cements), with application to low pH cements formulated for the seal zones. Andra today has a well-characterised range of low pH concrete formulations which are also being monitored during the course of the underground laboratory experiments (see FSS experiment).

Scientific outlook

Here we identify several essential points on which research is being carried out to improve the overall understanding of the behaviour of the repository elements.

Corrosion kinetics of low alloy steel metal components and the coupling with the hydraulic behaviour of the vaults in the production and migration of gases. The degree of uncertainty surrounding the corrosion kinetics of low alloy steel components of HLW vaults (lining and over-pack) is still high; more specifically, there is as yet no complete explanation for the evolution of corrosion kinetics which are at first high and then fall or even remain constant over time.

Mechanical behaviour of structures and repository
The representation of the damaged zone as a fractured environment and the long-term deferred argilite deformation rates are two avenues for work involving both experimentation and numerical simulation. The saturation of the seals is today primarily evaluated using simplified representation models of the hydromechanical behaviour of the pellet assemblies. The specific local and transient effects during saturation must more specifically be evaluated to consolidate the design domain adopted and ultimately the control of the phenomenological evolution of the seals.

Observation-monitoring of the repository
Significant progress has been made in the field of R&D on sensors (optical fibres, spectrometers, miniaturisation, wireless transmission). Efforts must be continued, more specifically to harden the sensors, ensuring their durability and independence, but also to develop means of merging the data that will be acquired during operation of the repository and decision-making systems.

Micro-nano approach to processes
Certain Thermo Hydro Mechanical and Chemical (THMC) processes, notably those taking place at the interfaces, require a small scale approach in order to improve our understanding of them. Work will therefore be needed for modelling and quantifying these processes. This research will in particular be carried out in a project supported by the cross-cutting NEEDS programme.

Storage research

There is extensive industrial experience feedback from the storage of packages of HLW and ILW-LL waste. The existing storage facilities have the capacity for additional waste. However, new storage needs are gradually appearing, with the overhauls being carried out on the installations, future waste production and changes to packaging. The requirements will eventually also change with the commissioning of Cigeo.

The studies and research coordinated by Andra since 2006 aimed both to identify these new requirements and propose technical answers. To do this, they explored the different aspects of the complementarity between storage and disposal. It thus became apparent that the operational complementarity between a storage facility and the disposal repository could involve the ability to function for periods of up to a century and to adapt capacity by means of a modular approach.

The studies and research focused on the engineering of the storage facilities and their phenomenological behaviour. Avenues for improvement and innovative technical options were examined. Industrial experience feedback from Areva, CEA and EDF and the results of previous research (that by CEA on long-duration storage and by Andra on disposal) acted as the starting point.

The prospect of an operating lifetime of a hundred years means that emphasis must be placed on the ease of maintenance of the equipment and structures of the storage facility, as well as the accessibility of the waste packages so that they can be monitored in-situ or removed for examination. For storage of any packages removed from disposal, it may be useful to be able to accommodate packages of various types in the same facility, in their primary form or placed in disposal over-packs.

In January 2013, Andra sent the Government a report summarising the studies and research it coordinated on the subject of storage [Andra report C.RP.ADPG.13.0001]. The decree of 27th December 2013 establishing the PNGMDR prescriptions tasked Andra with continuing to collect and build on the lessons learned from the construction and operation of the existing installations or those under development, to continue with research into the behaviour of the materials used to build the storage structures and the packaging materials and monitoring techniques, with a view to optimising durability, monitoring, heat removal and, if necessary, the versatility of these storage facilities.

Andra was also asked to look more closely at the storage concepts linked to reversibility, more specifically taking account of the condition of the packages retrieved from the repository. Andra thus supplemented its bunker storage studies derived from the NUHOMS© concept proposed by Areva, in which each concrete bunker, cooled by natural convection, contains a canister with or without over-pack.

Based on the results of all of its studies and research and after consultation with Areva, CEA and EDF, Andra submitted recommendations at the end of 2014 for the design of storage facilities to complement disposal[234]. These recommendations more particularly concern the choice of materials as related to the durability of the storage facilities, the monitoring systems and the design of storage facilities with regard to disposal reversibility.

On the whole, the storage concept studies conducted from 2006 to 2014 are characterised by their generic nature with regard to the packages to be accepted and the location of the facility. They identified a number of innovations which could apply to future installations. At this stage, Andra considers that no significant gains could be made from more detailed engineering designs for generic future storage facilities.

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[234] The report is available on the websites of ASN and the Ministry responsible for energy: http://www.asn.fr/Informer/Dossiers/La-gestion-des-dechets-radioactifs/Plan-national-de-gestion-des-matieres-et-dechets-radioactifs/PNGMDR-2013-2015 ;

- http://www.developpement-durable.gouv.fr/Rapports-realises-au-titre-du,43049.html.

The cooperation between Areva and Andra on the vitrified waste storage extension at La Hague (EEVLH) showed the benefit of concerted action to integrate the results of research into industrial projects to extend existing facilities or create new ones. In the particular case of E-EVLH, considerable work was done by Andra and Areva to integrate advances in research into the design of this facility. This work means that an increased lifetime for the facility can be envisaged.

Outlook

With regard to the definition of storage concepts linked to reversibility, studies are still to be carried out on the management of degraded primary packages (in particular of ILW-LL waste, which could have been removed from the repository), in particular concerning the design and sizing of the means for repackaging degraded primary packages in the Cigeo surface installations.

With regard to research on near-surface storage facilities, the technical data used as the basis for Andra's conclusions in its report submitted in 2013 need greater clarification in order to be able to rule on the pertinence of definitively abandoning this design option.

Continued research on generation IV fast neutron reactors and the closed fuel cycle

Purpose and implications of the research

Fast neutron reactors (FNR) offer a number of advantages in addition to the existing thermal neutron reactor systems (such as the existing fleet of PWRs in France):

- they can make unlimited use of the plutonium produced by water reactors or by themselves. France today recycles plutonium in the form of MOx, after its extraction from spent fuel in La Hague. However, the irradiated MOx fuel is not reprocessed: the plutonium it contains can only be efficiently used in fast neutron reactors;
- by making it possible to reuse all the uranium extracted from the ground, they multiply by a factor of about a hundred the energy that can be extracted from a given mass of natural uranium;
- once the operational stock of plutonium has been created, FNRs are able to dispense completely with natural uranium. They can then be supplied with depleted uranium, an abundant residue from enrichment operations currently with no commercial value and present in large quantities in France as a result of the operation of thermal reactors;
- the fast neutron spectrum can allow transmutation of the minor actinides and thus envisage a possible reduction in the inventory of these radionuclides in the waste and therefore its radiotoxicity, if this option is chosen following an analysis of the advantages and drawbacks of the operation.

FNRs thus make it possible to envisage a closed cycle strategy for managing the substances present in the spent fuels from a fleet of thermal neutron reactors, or a homogeneous FNR fleet. Among the various FNR concepts identified, the sodium-cooled fast neutron reactor series (FNR-Na) is the most mature and benefits from considerable operating experience feedback, which is why CEA chose it as the reference concept on which R&D efforts are to be focused in order to improve safety and operability, meet the objectives set by the 2006[235] Act and develop a generation IV reactor prototype.

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[235] 28th June 2006 Programme Act 2006-739 on the sustainable management of radioactive materials and waste.

This aim was given tangible form with the launch of the ASTRID programme within the framework of the investing in the future programme (CEA-State Agreement signed in 2010). The file presented in 2012 by CEA[236] in accordance with the milestone set in the 28th June 2006 Act on the sustainable management of nuclear materials and waste presents technological options for the ASTRID project and the FNR-Na plant series.

As ASTRID is intended to pave the way for a generation IV fast neutron reactor, ASN's letter of 10th April 2014 places particular emphasis on *"the need for this fourth generation to provide significant safety gains by comparison with the third generation and for ASTRID to allow effective testing of the reinforced safety options and measures"*. In an appendix to this letter, it also asks CEA to specify – in particular in its future DOS (safety options file) – whether it envisages *"carrying out minor actinides transmutation tests and assessing the impact of these tests on the general safety objectives"*.

ASTRID is at present expected to contribute to the qualification of complete transmutation of fuel assemblies in homogeneous mode and/or heterogeneous americium mode and/or of fuels dedicated to the increased consumption of plutonium. The programmes run in ASTRID should thus lead to sufficient industrial qualification for construction – if this choice is made at the relevant time – of industrial reactors carrying out transmutation or increased consumption of plutonium.

CEA intends to continue with design studies for the ASTRID prototype and the associated cycle workshops, with the aim of consolidating significant progress in terms of safety, demonstrating plutonium multi-recycling and depleted uranium recycling options and determining the prospects for an efficient industrial system.

In its June 2015 report, the National Review Board (CNE2) observes that *"R&D for running the Astrid programme is making constant progress"* and again recommends that *"sufficient resources be allocated in order to meet the calendar enabling the DAC [creation authorisation application] to be submitted in 2019"*. It also recommends that CEA:

- *"reinforce R&D in the fields which are to provide vital data to underpin the creation authorisation application for Astrid, in particular concerning the sodium-gas exchangers, the reactor coupling to the gas turbines and operational monitoring"*;
- *"continue to strengthen the ties between the industrial partners in order to see this project through to completion"*.

Recycling of uranium and plutonium

As described in the previous part, fast neutron reactors are the key component in a **closed cycle** strategy allowing efficient and sustainable management of the reusable materials present in spent fuels, that is uranium and plutonium (**multirecycling of plutonium** stabilises the stock of plutonium by recycling spent MOx fuels). This opens up the prospect of nuclear systems that are sustainable in the long term, consume less natural uranium and generate a smaller volume of waste with less long-term toxicity.

The ASTRID generation IV sodium-cooled fast neutron reactor is designed to provide a demonstration on a sufficient scale (600 MWe) of the technological advances identified to take this technology to the expected level, more particularly in terms of **safety** and **operability**.

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[236] This report is available on the CEA website: http://www.cea.fr/energie/rapport-sur-la-gestion-durable-des-matieres-nucl-106009.

Operating experience feedback from the first decade of ASTRID operations could then allow the **gradual deployment** of industrial sized reactors, at a rate which will depend on energy market conditions and on materials cycle decisions, in other words no earlier than the end of the 2040 decade. Areva, EDF and CEA carried out a joint study aimed at analysing and evaluating various increasingly ambitious "increments" for the deployment of generation IV fast neutron reactors in the French NPP fleet.

These "increments", detailed in the report sent out by CEA in June 2015, are as follows:

- Increment A: "Mono-recycling of spent fuels in PWRs" (current cycle)
- Increment B: "Recycling of spent MOx fuels" (stabilisation of storage of spent MOx fuels)
- Increment C: "Stabilisation of the total plutonium inventory by multi-recycling"
- Increment D: "Independence from natural uranium"

This gradual deployment must be accompanied by an R&D programme concerning the development of both fast neutron reactor technologies and fuel cycle technologies.

Studies for deployment of FNRs in the French NPP fleet (Areva – EDF – CEA study)

In its letter of 10th April 2014, ASN considers that *"to be authorised, the ASTRID reactor shall clearly demonstrate a level of safety at least equivalent to that of the EPR type reactors and take account of the lessons learned from the Fukushima Daiichi accident"*.

The ASTRID studies have since 2010 been carried out with CEA as the owner, with financing from Investing in the Future Programme (PIA) subsidies, without which the Astrid programme could never have started, along with sundry external financing (European PCRDT projects, then H2020). The French and international industrial partners taking part in the studies also make a contribution in kind, in that they carry out a part of the studies at their own expense.

Today, more than 600 people are working on ASTRID R&D and engineering, half at CEA and the rest among the 14 industrial partners.

In terms of planning, the preliminary design studies began in 2010. They are split into 3 phases:

- The purpose of the first phase of the conceptual design, referred to as AVP1, was to analyse the available options, in particular the most innovative, for selection of the reference design by the end of 2012. This first phase was completed in accordance with the schedule and CEA reported to its supervisory ministers at the end of 2012;
- The second phase of the conceptual design, referred to as AVP2, started in January 2013. It aims to consolidate the design so that by the end of 2015 a complete and coherent preliminary design is available;
- The detailed design phase is then planned as of 2016, with a review at the end of 2017 to enable the rest of the detailed design studies to be organised and, at the end of 2019, prepare for the decision to be made for performance of the final design and then construction.

The years 2016-2017 will be more particularly devoted to technico-economic optimisation of the reactor, continuation of studies on the innovative technical options, combined with extensive R&D content (experimentation, validation of codes) and in-depth studies of certain components to increase the level of technological maturity and reduce costs.

With regard to large-scale collaboration, it is worth mentioning the significant participation of Japan since 2014, with which discussions have started concerning a significant contribution by the Japanese Government and electrical utilities in the construction of ASTRID.

Fuel cycle R&D

The aim is to support the development of the ASTRID programme by developing appropriate fuel cycle technologies for multirecycling of uranium and plutonium; this primarily entails:

- adapting the spent fuel processing or MOx fuels fabrication technologies today in use at La Hague and in MELOX, to the fuels of the generation IV fast neutron reactors;
- improving technologies: this does not mean looking to improve current separation performance but rather seeking to obtain this same level of performance in constantly more favourable safety and economic conditions; the economic efficiency issue is increasingly acute with the prospect of nuclear systems in which recycling would be systematically used.

The possibility of multi-recycling of uranium and plutonium in an NPP fleet in which fast neutron reactors were gradually deployed would require the following in turn:

- processing of the MOX-PWR fuels today in storage, for recovery of the reusable materials (the plutonium in particular) they contain (industrial campaigns concerning nearly 70 tonnes of spent MOx fuels, have enabled the feasibility of the principle of such operations to be verified);
- the fabrication of MOX-FNR fuels from the recovered plutonium;
- processing (recurrent in order to achieve multi-recycling) of spent MOX-FNR fuels.

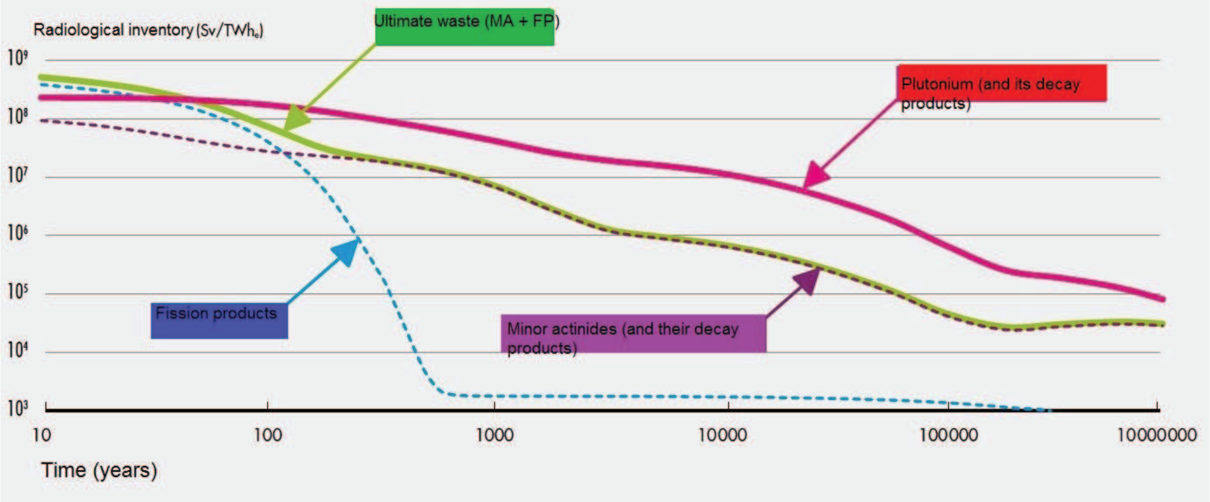
The purpose of the research carried out on this subject therefore concerns first of all the adaptation of the technologies to high levels of plutonium traffic and concentrations and to characteristics (in particular isotopic) that are different from those encountered in the previous experiments mentioned above. The implications for the management of certain risks such as criticality therefore need to be considered and special technological arrangements with appropriate geometries could prove necessary. Certain aspects in how the technologies are implemented must also be adapted (in particular with remote-operation devices adapted to a radiologically more demanding isotopic vector of the plutonium). The specific aspects of MOX-FNR fuels also imply modifications to certain steps in the treatment process: this is the case with the dissolution operation which, in order to be quantitative, requires adaptation of the usual operating conditions; one of the main avenues for research in this field concerns the development of an additional step to “digest” residues rich in plutonium which could persist following the fuel dissolution step. The concept was demonstrated in the laboratory using actual samples of spent MOx fuels and a significant rise in the level of plutonium recovery was measured.

Another essential avenue for research is to make the operations more compact (by simplifying the individual operations or reinforcing their integration), increasingly safe and generating less effluent and waste. One of the main research programmes in this field is to develop a process for recovery and purification of uranium and plutonium, with a drastically simplified principle: design of new extracting molecular architectures (initial experiments were carried out at the end of 2014 on actual spent fuel samples) leading to extremely encouraging prospects (possibility of carrying out uranium and plutonium recovery and purification in a single cycle).

Finally, a significant number of the studies in this field concerns the installations that will be needed for the Astrid demonstrator materials cycle; at this stage efforts are mainly focused on the design of the unit which will be manufacturing the first ASTRID cores (this is evidently the most pressing need, as Astrid fuel recycling can take place about ten years after reactor criticality). Several options are still under study for this core manufacturing unit (or AFC) and the technico-economic assessment of these options is being carried out in partnership with Areva, the aim being to provide a range of options in 2015 and a preliminary design by 2019.

Partitioning and transmutation of the minor actinides

Waste that is today vitrified contains fission products and minor actinides, which are residues from processing operations to recycle the uranium and plutonium. The radioactive half-life of most of the fission products is relatively short, unlike that of the minor actinides and their decay products. Although they only represent about one thousandth of the mass of the spent fuels, these minor actinides (mainly neptunium, americium, curium) are (either themselves or via their decay products) the main contributors to the radiotoxicity of the ultimate waste after a century (once most of the fission products have become transformed into stable isotopes). This led to the elimination of these elements being envisaged, by partitioning and then transmutation within a FNR (which offers favourable characteristics in this respect).



Contribution of the various components to the radiotoxicity of spent fuel (Source: CEA)

Americium was identified as the first target for a partitioning-transmutation strategy, the primary goal of which would be to reduce the long-term harmfulness of the ultimate waste. In the light of the results produced by CEA at the end of 2012, americium appeared to be the main contributor to radioactivity and residual heat in the final waste (vitrified waste) after a century; in its annual report N°8, the National Review Board recommends that “active and structured research” be maintained on this subject.

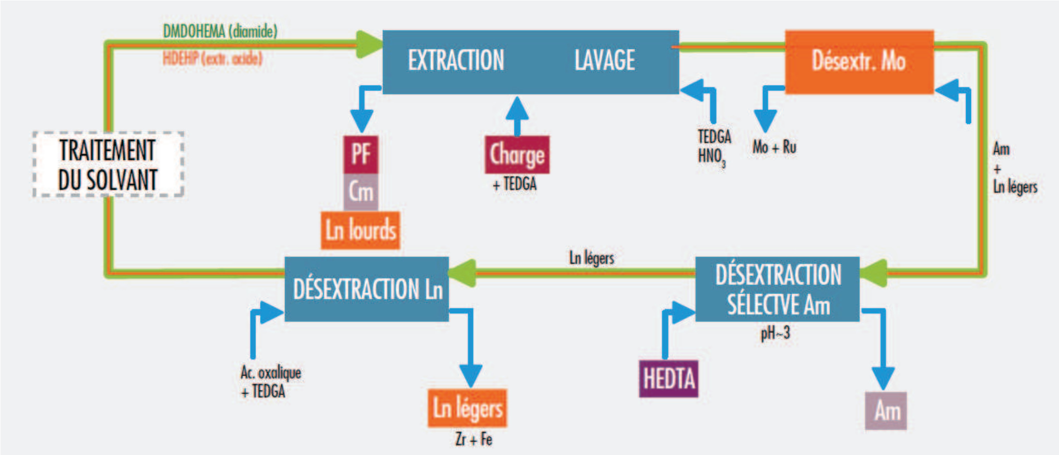
It is important to recall that this only actually makes sense in the context of multirecycling of plutonium (this latter would be the main contributor to the radiotoxicity of the residue, far ahead of americium, if this were not to be implemented – for example in the event of direct disposal of the spent MOx fuels). It should also be recalled that the minor actinides other than americium do not have equivalent long-term harmful effects, whereas some of them (in particular curium) have “immediate” harmful effects (radiological, thermal) which seriously penalise any particular treatment operation.

In this respect, in its opinion 2013-AV-0187 of 4th July 2013 on the transmutation of long-lived radioactive elements, ASN considered that “the expected gains from the transmutation of minor actinides in terms of safety, radiation protection and waste management do not appear to be decisive given in particular the resulting constraints on the fuel cycle facilities, the reactors and the transport operations, which would involve highly radioactive materials at all stages of the process. This would particularly be the case with the transmutation of curium”. These terms were recalled in its opinion of 25th February 2016, in which it added that “no justification for the continuation of studies on partitioning and transmutation can be found in nuclear safety or radiation protection.”[237]

The estimated impact of the transmutation of americium on the footprint of the high level waste repository was a reduction by a factor of more than 7 (in addition to that already resulting from the recycling of plutonium, by a factor of about 3). An additional analysis is currently under way to examine to what extent (and in what direction) changes to disposal concepts today being envisaged (more particularly to take account of additional thermomechanical effects within the structure) could modify this evaluation.

Partitioning research therefore focuses more on the possibility of recovering the americium downstream of uranium and plutonium recovery.

A process known as “EXAm” (for Extraction of Americium) was designed and experimented in the laboratory. This process, which is made complex by the double separation one is seeking to carry out in a single step (separate the americium from the fission products and separate the americium from the curium), was modified on a number of occasions, both to improve separation performance and to take account of industrial criteria (such as the advantage of working on sufficiently concentrated solutions in order to limit the volume of the solutions and the size of the equipment necessary); americium recovery rates of better than 99% were measured and various solutions were tested to improve americium purification with respect to curium.



Schematic of the EXAm process (Source: CEA)

The next step is to perform a test on actual spent fuel samples from the process optimised in this

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[237] The ASN opinions of 4th July 2013 (2013-AV-0187) and 25th February 2016 (2016-AV-0259) on the management of high level and intermediate level, long-lived waste, are available on the ASN website: http://www.asn.fr, heading « les actions de l’ASN », « la réglementation », « bulletin officiel de l’ASN », « avis de l’ASN ».

way: this is the experiment referred to as "integral", which consists in recovering the americium from a sample of about 4 kg of spent fuel for subsequent transmutation in the ATR test reactor (Idaho, USA). The first (usual) steps of dissolution then recovery of the uranium and plutonium were carried out. At the end of 2015, the americium recovery steps will be started, followed by the fabrication of oxide pellets for insertion into the reactor, which should take place in 2019.

Transmutation studies are looking in particular at the concept of americium-bearing blankets (AmBB), which consists in carrying out transmutation in specific objects around the periphery of the FNR core (uranium oxide pins, charged to about 10% with americium). The advantage of this option is that it separates the transmutation operations from the operation of the reactor, which is beneficial in a number of ways (in particular in terms of safety, as the americium can be penalising if introduced into the core in significant quantities) and – if transmutation were to be adopted – it could be a solution for gradual implementation on certain reactors in the fleet.

Research in this field is however suffering from the lack of FNR availability for fully representative experimentation. In this context, the focus turns to "analytical" irradiations in an experimental reactor, to study the important phenomena which regulate the behaviour of such AmBB during irradiation. One of the main questions concerns the behaviour within the material of helium (generated in large quantities in the transmutation of americium isotope 241): this is the subject of the Marios and Diamino irradiation programmes, carried out in the HFR (Petten, Netherlands) and Osiris (Saclay) reactors respectively and aiming to cover all the operating parameters (temperature in particular) of a blanket around the FNR periphery. The first examinations are today being carried out with the Marios experiment (ex-pile), while Diamino irradiation is continuing: the first overall results will be available in 2016, before the planned experimentation in ATR mentioned above.

Research is also looking at processes to produce such objects: the conversion (production of americium oxide from solutions produced by the separation steps) and fabrication steps are undergoing development and experimentation in CEA's Atalante facility in Marcoule. The aim will be on the one hand to transpose to americium the processes and technologies today used to produce mixed uranium and plutonium oxide pellets (precipitation then calcination of the oxalate, before fabricating MOx pellets using powder metallurgy). New avenues will also be explored, more specifically to minimise the generation of fine particles leading to potentially significant detrimental effects in the case of americium powders.

The clearly stated goal of developing the availability of mineral raw materials in Europe, by working mining deposits and recycling end-of-life products, means that the development of metal extraction processes are being examined.

The studies carried out under priority 1 of the 1991 Act and then the 2006 Act, enables the research stakeholders (CEA in particular) to develop extensive expertise in the development of innovative hydrometallurgy processes (from the molecule to the processes and technologies utilised); in CEA's Marcoule centre, this led to the creation of the Marcoule Institute of Separation Chemistry and of LABEX Chemisyst, which together can address needs outside the nuclear sector.

This recently resulted in a project to create a European Hydrometallurgical Institute (EHI) an umbrella organisation for:

- A research network comprising academic and industrial researchers from the metals extraction sector, in order to define the sector's innovation needs. This network was created at the end of 2014 in the form of a non-profit association called PROMETIA;

- An open technological platform to enable extraction processes to mature prior to industrialisation, the construction of which should begin at the end of 2015.

Main research facilities used for the studies carried out under the PNGMDR

CEA facilities

Facilities for studying treatment processes

ATALANTE (Marcoule)
The ATALANTE facility is a set of high-level laboratories at CEA Marcoule intended for studies on the fuel cycle. This laboratory comprises 7 shielded process lines and 17 laboratories with glove boxes, in which research is carried out into separation processes, preparation of fuels or targets for transmutation, the confinement of ultimate waste and the long-term behaviour of waste packages.

Laboratory G1 (Marcoule)
Laboratory G1, which comprises the Chimène active zone and the HEC hall, aims to develop technologies for implementing the treatment processes envisaged for the fuel cycle back-end, in addition to the processes being developed in the ATALANTE facility. This more specifically concerns technologies for the generation IV cycle.

Facilities for studying materials and fuels

LECA/STAR (Cadarache)
LECA is used to characterise the behaviour of irradiated fuel samples taken from fuel rods irradiated in the NPP fleet or in experimental reactors. This laboratory can refabricate short rods intended for experimental irradiation in a test reactor and intervenes downstream of the STAR laboratory, in which non-destructive examinations and drilling of whole irradiated rods from NPPs are carried out.

LECI (Saclay)
LECI is a laboratory mainly devoted to the physico-chemical, metallurgical and mechanical characterisation of irradiated metal materials. It provides data for predicting the lifetime of nuclear components and for qualifying new or improved materials able to comply with future conditions of use. Its reduced fuel characterisation capacity enables it to provide support to LECA/STAR in Cadarache.

LEFCA (Cadarache)
LEFCA carries out studies on uranium and on actinides (plutonium, americium, neptunium), in the form of alloys, ceramics or composites. These studies are necessary for the interpretation and comprehension of the behaviour of fuels in the reactor. The experimental capsules and assemblies intended for the irradiation tests are manufactured in this laboratory. It should be noted that LEFCA's research activities are being transferred to the ATALANTE facility.

Labo UO2 (Cadarache)
The UO2 laboratory, or the Laboratoire Bernard François dedicated to research on non-irradiated fuels. This laboratory is a complement to LEFCA and ATALANTE and is used to study the processes involved during fuel fabrication operations, up to the scale of several hundred grams. It

more specifically carries out studies for implementation of processes and technologies for the generation IV fuels.

Facilities for studying behaviour in the reactor

MINERVE (Cadarache)
MINERVE is an experimental reactor intended for neutronic studies primarily with a view to improving the complete nuclear data libraries for fuel arrays representative of different nuclear reactor types. This facility can be used for measurements on certain isotopes of interest, in particular for transmutation studies.

OSIRIS (Saclay) (final shutdown effective)
This experimental light water and open core type reactor, with a thermal power of 70 MW, went critical in 1966 and was then finally shut down on 16th December 2015. Over a period of nearly 50 years, this tool took part in the study of materials and fuels for present and future NPPs, but also produced radionuclides for medical and industrial applications.

RJH reactor (Cadarache) ***(under construction)***
RJH (Réacteur Jules Horowitz) is an experimental reactor for irradiation of materials, currently under construction on the Cadarache site. It is scheduled to take over from the OSIRIS reactor by 2021. This reactor, with a power of 100 MW, will offer an experimental irradiation capacity for studying the behaviour of materials and fuels under irradiation.

Facilities for studying the packaging of final waste

CD Hall (Marcoule)
The CD Hall carries out decontamination and packaging studies for the waste produced by the fuel cycle industry and by nuclear reactors, more particularly in the field of vitrification of fission product solutions (cold crucible, etc.), the development of new confinement matrices such as ceramics, the incineration of alpha rich fuel waste and the development of innovative technologies for certain types of waste (resins, organic waste, radioactive effluents of various origins) and the development of decontamination processes for solid materials such as concretes and effluents.

HERA Hall (Marcoule)
The HERA facility is used for research on the packaging and long-duration storage of high level, long-lived waste and for performing the demonstrations necessary for these long periods (300 years for storage). HERA thus combines research and development laboratories working on the topics of hydrogen production, the destruction and packaging of waste, post-operational clean-out and decommissioning of old facilities.

The CEA and Areva (Marcoule) LCV (Joint Vitrification Laboratory)
The LCV is a high-activity facility jointly run by CEA DEN/DTCD (Waste Processing and Packaging Studies Department) and Areva. This laboratory is dedicated to developing innovative processes for the vitrification of high level radioactive waste and for packaging and processing intermediate and low level waste using thermal processes. This facility is also used to study alternative packaging matrices such as ceramics or vitro-ceramics.

Radioactive waste characterisation facilities.

CHICADE (Cadarache)

The CHICADE facility is a platform for carrying out non-destructive examinations for the development and qualification of nuclear measurement systems, chemical and radiochemical analyses for R&D and, to support the CEA/Cadarache facilities, destructive examinations for the characterisation, repackaging and categorisation of waste.

LARC (Cadarache)

LARC is a radiochemical analysis laboratory carrying out radiological analyses of dosed alpha, beta, gamma and X-ray emitters on low to intermediate level samples, by liquid scintillation and gamma spectrometry, mineral and organic chemical analyses with determination of the major elements, using ion chromatography, capillary electrophoresis, UV/visible spectrometry, Fourier transform spectrometry, liquid chromatography coupled with a mass spectrometer and elementary and isotopic analyses of traces and ultra-traces by mass spectrometry and coupled plasma-mass spectrometry, but also direct analysis techniques coupled with a mass spectrometer.

Facilities for physico-chemical studies of radionuclides

Radioactive ICPEs at the DPC (Saclay)

The radioactive ICPEs at the DPC (Physico-Chemistry Department) aim to cover several disciplinary fields on behalf of research programmes to support the nuclear sector, including thermodynamics, thermochemistry, electrochemistry, reactivity of surfaces, corrosion, transport properties at the interfaces, and coupling between these fields. The aim is to understand, model and predict the behaviour of materials and radionuclides (speciation, migration) over the long and very long term in their environments, including that of storage and disposal of waste packages.

Areva facilities

HRB (Beaumont research hall): laboratory scale tests and inactive pilot

Its primary role is to assist customers with their technological development strategy, but also operational research linked to Areva projects.

Operational research is initiated in response to problems encountered in the field, when a project requires development of a technology, a process, or confirmation of a technical choice.

TRIADE: laboratory scale tests and inactive pilot

TRIADE more specifically carries out research and optimisation work on processing, delicensing, packaging systems, according to local and national technical and economic conditions.

This field is supplemented by the study and management of the harmlessness of the processes according to the final purpose of decontamination.

Creusot technical centre: (inactive technological scale)

The Creusot Technical Centre develops techniques, methods and tools to improve the design, construction, operation and maintenance of both existing NPPs and those of tomorrow.

- New products and services: Solutions helping to bring down operating costs, improve NPP availability and reinforce reliability and safety;
- Optimisation of components manufacturing: Reduction of components manufacturing costs, increased manufacturing productivity, workstation ergonomics and personnel safety, robotics solutions;
- Development of new reactors: Reactors for generation IV NPPs, long-term technologies (ITER, research reactor).

SEPA: Design, Process and Analysis Department) (laboratory or pilot scale, active U)
SEPA is in charge of defining and implementing innovative, sustainable processes in the field of ore processing, metallurgical units, analysis laboratories, pilot test halls, test benches.
Its goal is to improve the performance of current processes and define new ones.

EDF facilities

No active tests are performed by EDF and all the laboratories are located on the EDF Lab "les Renardières" site:

Civil Engineering Laboratory to study the behaviour of the immobilisation grout for the C1PG packages.

LESCA laboratory to study the dissolution of B4C pellets in a cement medium (work performed and defined pursuant to the PNGMDR requests concerning sodium waste).

Corrosion laboratory to study the behaviour of glasses in a geological repository (study of the influence of the repository environment materials).

MERCURE Pilot for full-scale tests to demonstrate that packages containing ion exchange resins meet the specifications set out by Andra (packages intended for the Aube repository).

Andra facilities

The Bure underground laboratory for in-situ observation and measurement of the properties of the Callovo-Oxfordian clays and the development of engineering techniques (excavation – ground support) in preparation for the Cigeo project.

Appendix 5: Inter-governmental agreements concluded by France concerning the management of spent fuel or radioactive waste (agreements in force as at 31st December 2015, given in chronological order)

1 – Japan:

a) Cooperation agreement between the Government of the French Republic and the Government of Japan for the use of nuclear energy for peaceful purposes, signed in Tokyo on 26th February 1972.

b) Protocol modifying this cooperation agreement (set of three annexes, a report and an exchange of letters), signed in Paris on 9th April 1990.

2 – Switzerland:

Exchange of letters constituting the agreement between France and Switzerland concerning the contracts concluded between COGEMA and Swiss companies for the processing by COGEMA of certain quantities of spent fuel from Switzerland, signed on 11th July 1978.

3 – Netherlands:

a) Agreement in the form of an exchange of letters between the Government of the French Republic and the Government of the Kingdom of the Netherlands, concerning the processing in France of spent fuel elements, signed in Paris on 29th May 1979.

b) Modifying agreement dated 9th February 2009, published in the *Journal Officiel* by decree 2010-1167 of 30th September 2010

4 – Sweden:

Exchange of letters constituting the agreement between France and Sweden concerning the contracts concluded between COGEMA and the Swedish SKBF company for the processing by COGEMA of certain quantities of spent fuel from Sweden, signed on 10th July 1979.

5 – Spain:

Exchange of memoranda constituting the agreement between France and Spain on radioactive waste from spent fuels produced by the Vandellos I NPP, signed on 27th January 1989.

6 – Australia:

Arrangement between the Government of the French Republic and the Government of Australia concerning the implementation of a processing contract concluded between COGEMA and the Australian Nuclear Science and Technology Organisation (ANSTO), in the form of an exchange of letters, signed in Paris on 27th August 1999.

7 – Italy:

Agreement between the Government of the French Republic and the Government of the Italian Republic concerning the processing of 235 tons of Italian spent fuel, signed in Lucca on 24th November 2006 and published in the *Journal Officiel* by decree 2007-742 of 7th May 2007

8 – Germany:

Agreement in the form of an exchange of letters between the Government of the French Republic and the Government of the Federal Republic of Germany concerning the transport from the French Republic to the Federal Republic of Germany of packages of radioactive waste from processing of spent fuel, signed in Paris on 20th and 28th October 2008 and published in the *Journal Officiel* by decree 2008-1369 of 19th December 2008

9 – Monaco:

Agreement between the Government of the French Republic and the Principality of Monaco concerning the entry into French territory of radioactive waste from Monaco, signed in Paris on 9th November 2010 and approved by Act 2013-580 of 4th July 2013 (enacted in the *Journal Officiel* of 6th July).

10 – Netherlands:

Agreement between the Government of the French Republic and the Government of the Kingdom of the Netherlands, concerning the processing in France of Dutch spent fuel elements, signed in The Hague on 20th April 2012 and published in the *Journal Officiel* by decree 2013-1285 of 27th December 2013.

11 – Belgium:

Agreement between the Government of the French Republic and the Government of the Kingdom of Belgium, concerning the processing of Belgian spent fuels at La Hague, signed in Paris on 25th April 2013 and published in the *Journal Officiel* by decree 2014-835 of 23rd July 2014.

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