National Inventory of Radioactive Materials and Waste

2015
FOCUS ON

ANDRA
French national radioactive waste management agency

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RÉPUBLIQUE FRANÇAISE
MINISTÈRE
DE L'ÉCOLOGIE,
DU DÉVELOPPEMENT
DURABLE
ET DE L'ÉNERGIE

EDITORIAL

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In the early 1990s, the French government set up Andra, the National Agency for Radioactive Waste Management, and tasked it with identifying and designing safe management solutions for all French radioactive waste, in order to protect present and future generations.
As part of this commission, Andra is responsible for producing an annual inventory of all radioactive materials and waste in the country, to provide a comprehensive overview of their type, quantity and location. As defined by the French Law of 28 June 2006, Andra acts in the public interest, updating and publishing this information every three years in a document referred to as the *National Inventory of Radioactive Materials and Waste*.

This Inventory is a key reference resource, and helps ensure good management of current and future French radioactive waste. For the sake of transparency, Andra established a multidisciplinary steering committee to monitor preparation of the *National Inventory*. Under the direction of Andra's Chief Executive Officer, this steering committee includes representatives of French government bodies (ministries, nuclear safety authority, high committee for transparency and information on nuclear safety) and representatives of waste producers, civil society and environmental protection organisations.

The 2015 edition of the *National Inventory* covers the radioactive waste present in France on 31 December 2013, as well as forecasts of expected waste quantities for 2020, 2030 and at the end of facility lifetime. A prospective study is also included, with two alternative scenarios regarding the long-term future of France's nuclear facilities and energy policy. The Inventory also presents radioactive materials kept in storage pending their transformation into value-added products.

For the 2015 edition of the *National Inventory*, Andra set out to make the data accessible to as wide a readership as possible. A dedicated website www.inventaire.andra.fr was created. This site will be updated each year and paves the way for the implementation of an open data policy concerning the *National Inventory* data.

We hope you enjoy reading this fifth edition.

François-Michel Gonnot — Pierre-Marie Abadie

THE 2015 INVENTORY: THERE'S MORE...

This document is the public version of the *National Inventory*.
The complete *National Inventory* also includes technical documents that provide a comprehensive set of data on radioactive materials and waste present in France at the end of 2013:

Essentials

Presentation of the global 2015 *National Inventory* figures to provide a basis for the PNGMDR (radioactive materials and waste national management plan) updated every three years.

Synthesis Report

Detailed presentation of all existing and future radioactive materials and waste in France.

Catalogue of Families

A presentation of all radioactive waste grouped by family, each family covering waste with similar characteristics.
Available in French only.

Geographical Inventory

The locations of radioactive waste in France.
Available in French only.

The *National Inventory of Radioactive Materials and Waste* is available online:
WWW.INVENTAIRE.ANDRA.FR

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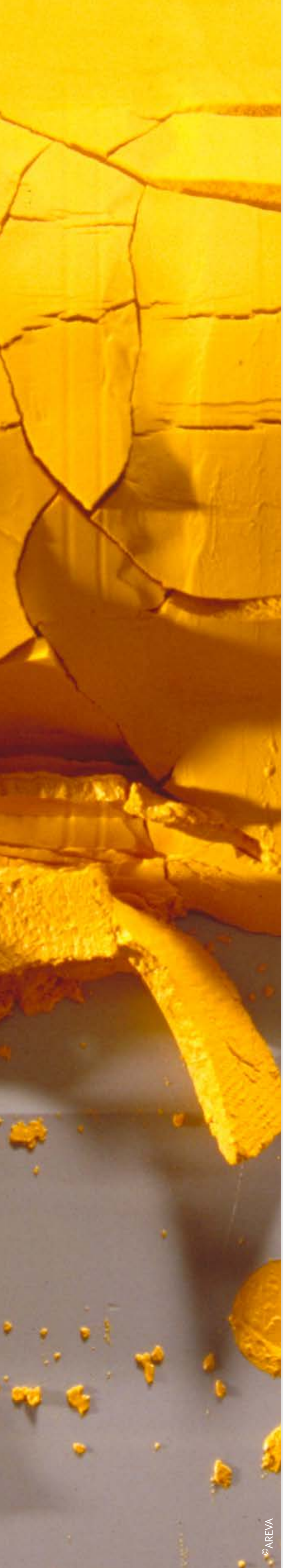

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CHAPTER 1

WHAT CONSTITUTES RADIOACTIVE MATERIALS AND WASTE?

1. INTRODUCTION

Many industries make use of the properties of natural or artificial radioactivity. These uses generate waste and other materials, some of which is radioactive. The vast majority is similar to conventional waste, such as tools, clothing, plastics, scrap metal and rubble. However, its radioactivity presents a health risk and special management methods must be used.

RADIOACTIVITY IS USED PRIMARILY IN THE FOLLOWING FIVE INDUSTRIES

1

Nuclear power industry

Mainly includes power plants for electricity production, as well as plants for nuclear fuel fabrication and processing (extraction and processing of uranium ore, chemical conversion and enrichment of uranium concentrates, fuel fabrication, spent fuel reprocessing and recycling of some of the material extracted).

2

Research

For civil nuclear applications along with medical, agronomy, chemistry, biology, and nuclear physics and particle laboratories.

3

Defence industry

Mainly military and deterrence activities, including nuclear powered ships or submarines and the associated research activities.

4

Industries other than nuclear power

Rare earth mining, fabrication of sealed sources, and various other applications such as weld inspection, medical equipment sterilisation, food sterilisation and preservation, etc.

5

Healthcare

Diagnostic and therapeutic activities (scintigraphy, radiotherapy, etc.)

HIGHLY VARIED WASTE

Radioactive waste consists of substances for which no later use is envisaged. It contains a mixture of radionuclides (such as caesium, uranium, iodine, cobalt, radium and tritium). The nature of these radionuclides determines the level and radioactive lifetime of the waste.

To facilitate management, radioactive waste is classified according to various criteria:

- its radioactivity expressed in becquerels (Bq) per gram; also called "activity". The level of waste radioactivity can be very low, low, intermediate or high.

- lifetime, determined by the half-life of each radionuclide the waste contains; to simplify, the radioactivity of short-lived waste comes mainly from short-lived radionuclides (half-life ≤ 31 years), whereas long-lived waste contains a significant quantity of long-lived radionuclides (half-life greater than 31 years, up to hundreds of thousands of years).

Radioactive waste is classified into five categories:
- very low-level waste (VLLW)
- low- and intermediate-level short-lived waste (LILW-SL)
- low-level long-lived waste (LLW-LL)
- intermediate-level long-lived waste (ILW-LL)
- high-level waste (HLW)

VERY SHORT-LIVED WASTE

Certain types of waste, mainly from diagnostic or therapeutic applications in hospitals, contain very short-lived radionuclides. Their half-life is less than 100 days. They are consequently stored where they are generated, the time necessary for the radioactivity to fall to zero (a few days to a few months). They are then disposed of as conventional waste.

Measurement of the radioactivity of a piece of uranium ore

MATERIALS OR WASTE?

Unlike radioactive waste, radioactive materials are substances for which subsequent use is planned or intended, sometimes following processing.

Most of the materials are generated by the nuclear fuel cycle (*see page 28*). These materials mainly consist of uranium (natural, enriched or depleted), fuels (new, in use or spent), uranium and plutonium separated by spent fuel reprocessing, and recoverable materials from industries other than the nuclear power industry (mainly materials containing thorium).

Only radioactive waste is destined for disposal by Andra. However, radioactive materials are listed in the *National Inventory* because they may fall into the category of waste if not reused.

DEFINITION: RADIOACTIVITY

A natural phenomena discovered at the end of the 19th century, which involves certain unstable isotopes called radionuclides that decay by emitting radiation.

The radioactivity of a substance decreases naturally over time, at a rate that will depend on which radionuclides are present. Half-life refers to the time necessary for the quantity of radionuclides to be reduced by half: 8 days for iodine-131, 13 years for tritium, 31 years for caesium-137, 1,600 years for radium-226, and 5,700 years for carbon-14. For example, from a sample of 1 gram of caesium-137 only 0.5 grams would remain after 31 years. This sample would therefore be half as radioactive.

2. VERY LOW-LEVEL WASTE (VLLW)

Very low-level waste mostly comes from operational and dismantled nuclear facilities, but also from conventional industrial plants in various industries, such as chemicals, metallurgy, energy production, etc., which use naturally radioactive materials. Certain types of VLLW come from clean-up and rehabilitation operations on sites which were formerly contaminated by radioactivity. This category generally concerns inert waste, such as concrete, rubble and soil, as well as metallic waste.

In the coming years, a large portion of VLLW will come from the dismantling of nuclear power plants currently in use, nuclear fuel cycle plants, and research centres.

By the end of 2013, around **250,000 m³** of VLLW was already in disposal.

CURRENT AND FORECAST VOLUMES OF VLLW

2013	2020	2030
440,000	650,000	1,100,000

As disposed volume in m³

MANAGEMENT

Since 2003, VLLW has been disposed of at Cires (radioactive waste management, interim storage and disposal facility), operated by Andra in the Aube district (Eastern France). This is the first disposal facility in the world for this type of waste. Between 20,000 and 30,000 m³ of VLLW are disposed of there each year (*see page 33*).

Prior to disposal, VLLW is packaged according to type, either in big bags for ease of handling, or in metal containers.

Certain waste items may be subject to specific treatment:
- compaction for plastic and metallic waste, to reduce volume;
- solidification then stabilisation for liquid waste (contaminated water, sludge, etc.).

At the end of 2013, VLLW waste represented 440,000 m³, i.e.

- **30%** of the total volume of French radioactive waste already produced*;
- less than **0.000004%** of the total radioactivity of French radioactive waste;
- The level of radioactivity is generally less than **100 becquerels per gram.** The waste contains short-lived or long-lived radionuclides.

**Waste produced in France that is to be managed by Andra.*

Disposal of VLLW metallic waste in a cell at Cires

A FRENCH AND SPANISH EXCEPTION

Due to the very low radioactivity of this waste, most countries treat it as "conventional" waste. France, followed by Spain, has decided to manage it in a dedicated facility.

3. LOW- AND INTERMEDIATE-LEVEL SHORT-LIVED WASTE (LILW-SL)

Low- and intermediate-level short-lived waste is generally from the maintenance (clothing, tools, gloves, filters) and operation (treatment of liquid effluents or filtration of gaseous effluents) of nuclear power plants, fuel cycle plants and research centres.

Such waste also comes from hospital, university and research laboratories and from clean-up and dismantling operations.

At the end of 2013, around **810,000 m³** of LILW-SL was already in disposal at the Manche facility (CSM) and the Aube facility (CSA).

CURRENT AND FORECAST VOLUMES OF LILW-SL

2013	2020	2030
880,000	1,000,000	1,200,000

As disposed volume in m³

MANAGEMENT

LILW-SL was formerly disposed of at the Manche disposal facility, which has now closed and is monitored by Andra. Since 1992, LILW-SL has been managed at Andra's Aube facility (CSA) in Eastern France. This site, operated by Andra, receives around 10,000 m³ of waste each year.

Prior to disposal, most of the low-level waste undergoes treatment by compaction to reduce volume. It is then placed in metal or concrete containers.
LILW-SL packages comprise 15-20% radioactive waste and 80-85% encapsulation.a

A SYSTEM THAT HAS BEEN OPERATING FOR 40 YEARS

LILW-SL represents over 60% of radioactive waste currently produced in France (excluding waste handled by "historic" management methods). It was the first category to have a dedicated repository, managed by Andra, the CSM (Manche radioactive waste disposal facility), opened over 40 years ago.

Disposal of a LILW package in a cell at CSA

At the end of 2013, LILW-SL waste represented 880,000 m³, i.e.

- **60%** of the total volume of French radioactive waste already produced*;
- **0.02%** of the total radioactivity of French radioactive waste;
- The radioactivity level is generally between a few **100 becquerels and 1 million becquerels per gram.** LILW-SL contains primarily short-lived radionuclides (such as cobalt-60 or caesium-137) and may contain limited amounts of long-lived radionuclides.

**Waste produced in France that is to be managed by Andra.*

4. LOW-LEVEL LONG-LIVED WASTE (LLW-LL)

The LLW-LL category covers three main types of waste:

- Graphite waste from the operation and dismantling of the first nuclear power plants (GCR or gas-cooled graphite-moderated reactors) and certain experimental reactors that are now shut down. This type of waste has a radioactivity level between 10,000 and 100,000 becquerels per gram. The activity of graphite waste is mainly due to nickel-93, tritium and cobalt-60.

- Radium-bearing waste, which comes primarily from non-nuclear industrial activities, including certain types of research and the processing of ores containing rare earths. Other radium-bearing waste comes from the cleanup of legacy sites contaminated by radium. Andra is responsible for the security of these sites as part of the activities it performs in the general interest. The radioactivity of this type of waste is generally between a few tens and a few hundreds of becquerels per gram.

- Other types of LLW-LL like certain spent sealed sources (such as radium lightning conductors and smoke detectors), certain drums of bituminised sludge, and certain old radioactive objects that are found in private hands (such as radioluminescent watches and medical radium needles).

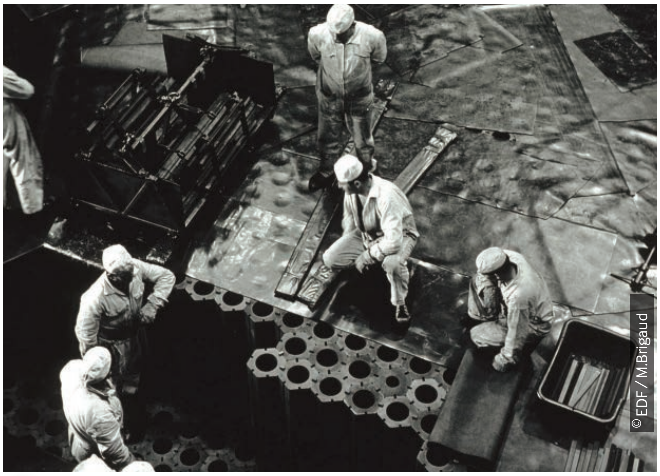
CURRENT AND FORECAST VOLUMES OF LLW-LL

2013	2020	2030
91,000	92,000	120,000

As disposed volume in m³

MANAGEMENT

LLW-LL is currently stored where it is generated or, for certain types of waste not from nuclear power production, at Cires (radioactive waste management, interim storage and disposal facility in the Aube district, Eastern France), pending a management solution. Andra has been tasked with conducting research and studies to develop disposal solutions for this type of waste *(see page 34)*.



Piling of graphite bricks during construction of the Chinon nuclear power plant

At the end of 2013, LLW-LL waste represented 91,000 m³, i.e.

- **6%** of the total volume of French radioactive waste already produced*;
- **0.01%** of the total radioactivity of French radioactive waste.

*Waste produced in France that is to be managed by Andra.

5. INTERMEDIATE-LEVEL LONG-LIVED WASTE (ILW-LL)

Nuclear power plants operate using fuels that are mainly composed of uranium. After several years in the reactor core, these fuels become less efficient. They are then reprocessed at the AREVA NC facility at La Hague (Manche, Northern France).
The metal structures surrounding the fuel are sliced into small sections to separate them from the material and residues that they contain. A major fraction of ILW-LL is composed of this metal debris (hulls and end caps) but some may also come from the reprocessing of the spent-fuel itself.
ILW-LL can also be components (other than fuel) from the inside of nuclear reactors or waste from maintenance and dismantling operations on nuclear facilities, workshops, laboratories, etc.

CURRENT AND FORECAST VOLUMES OF ILW-LL

2013	2020	2030
44,000	48,000	53,000

As disposed volume in m³

At the end of 2013, ILW-LL waste represented 44,000 m³, i.e.

- 3% of the total volume of radioactive waste in France already produced*;
- 2% of the total radioactivity of French radioactive waste;
- ILW-LL contains significant quantities of long-lived radionuclides. The radioactivity level is generally between 1 million and 1 billion becquerels per gram.

MANAGEMENT

To reduce its volume, a significant fraction of ILW-LL is compacted into pucks, which are then inserted into concrete or metal packages. Other conditioning methods could be used depending on the type of waste, such as cement or bitumen encapsulation, or vitrification.

The high level of radioactivity and the lifetime of ILW-LL necessitate disposal in a deep geological repository. Andra has been tasked with conducting research and studies to design a reversible disposal facility for this waste at a depth of 500 m; the project is known as Cigéo. While awaiting the creation of Cigéo, the waste is stored mainly on the sites where the packages are produced.

Metallic waste from the structures surrounding spent fuel (hulls)

6. HIGH-LEVEL WASTE (HLW)

HLW mainly comes from the reprocessing of spent fuel from nuclear power plants. During this reprocessing, spent fuels are dissolved in a chemical solution to separate the uranium and plutonium from the non-reusable residues. The highly-radioactive residues constitute HLW. They represent approximately 4% of spent fuel. They comprise fission products (such as caesium-134, caesium-137 and strontium-90), activation products (such as cobalt-60) and minor actinides (such as curium-244 and americium-241).
Such waste accounts for most of the radioactivity of the radioactive waste produced in France.

CURRENT AND FORECAST VOLUMES OF HLW

2013	2020	2030
3,200	4,100	5,500

As disposed volume in m³

At the end of 2013, HLW waste represented 3,200 m³, i.e.

- **0.2%** of the total volume of French radioactive waste already produced*;
- **98%** of the total radioactivity of French radioactive waste;
- HLW radioactivity is anywhere between **several billions and several tens of billions of becquerels per gram.** HLW contains various short-lived and long-lived radionuclides, some of which are very long-lived (such as neptunium-237 with a half-life of approximately 2 million years).

**Waste produced in France that is to be managed by Andra.*

MANAGEMENT

After separation from uranium and plutonium, HLW is incorporated in a glass matrix having a particularly high and durable confinement capacity. The mixture is poured into a stainless steel canister. An HLW package contains approximately 400 kg of glass and 70 kg of waste.

The level of radioactivity and the lifetime of this waste necessitate disposal in a deep geological repository. Andra has been tasked with conducting research and studies to design a reversible disposal facility for this waste at a depth of 500 m; the project is known as Cigéo. While awaiting the creation of Cigéo, the waste is stored mainly on the sites where the packages are produced.

IS SPENT FUEL WASTE?

In some countries, spent fuel from nuclear power plants is considered as waste and directly disposed of. In France, it has been decided that it be reprocessed to recover the reusable materials contained in these fuels; only the small non-reusable part (waste) is disposed of. Nevertheless, all spent fuel is included in the National Inventory so that its management could be considered if its reprocessing were no longer planned in France. Andra is also performing studies regarding the possibility of disposal in the Cigéo geological repository.

7. RADIUM-BEARING WASTE

When radioactivity was first discovered, the risks it presented were not well understood. A very keen interest in this phenomenon developed and gave rise to a "radium industry" during the interwar years. Radium was used to manufacture numerous everyday objects. Today, some of these objects may still be found in private hands, in collections or forgotten in attics. Andra collects and manages them. The former production sites for these objects may also be contaminated with radium. Making an inventory of these sites enables clean-up work to move forward.

SITES CONTAMINATED BY RADIOACTIVITY

A site contaminated by radioactivity is a site on which radioactive substances have been handled or stored in an uncontrolled manner, leading to the dispersal of these substances and presenting a potential risk for health and the environment depending on the later usage of this site.

Most contaminated sites in France are associated with past activities such as the extraction of radium for medical or health-and-beauty purposes, the manufacture and application of radioluminescent paints, or the processing of ores.

After the Second World War, many of these sites were forgotten and some were redeveloped for other activities or housing.

Some contaminated sites are associated with more recent activities. They have been secured and left as waste ground.

The French government has started a process for identifying such sites for remediation. When the entity responsible for a site does not meet its obligations, remediation is carried out by Andra. Funding is provided by government subsidy following a position issued by the French National Commission for Radioactivity Assistance (CNAR) on the use of this subsidy and on the need (or otherwise) for site clean-up.

At the end of 2013, **70 contaminated sites** had been found in France; most have been remediated, are in remediation or will be remediated in the future.

RADIOACTIVE OBJECTS OWNED BY PRIVATE INDIVIDUALS

After its discovery, radium was used to manufacture objects for everyday use (lipsticks, beauty creams, luminescent clocks, water fountains) as well as medical and paramedical equipment (such as radium needles).

In most cases, the owners of these objects (private individuals, collectors) are unaware of the dangers they present. Andra recovers these objects free of charge.

Every year, some 100 radioactive objects are collected by Andra.

Contaminated workshop prior to clean-up (Orflam factory in Pargny-sur-Saulx)

8. RECOVERABLE MATERIALS

Radioactive materials are substances for which subsequent use is planned or intended, if applicable following processing.
These materials mainly consist of uranium (natural, enriched or depleted), fuels (new, in use or spent), uranium and plutonium separated by spent fuel reprocessing, and recoverable materials from industries other than the nuclear power industry (mainly materials containing thorium).
They mainly consist of ores, sands and metals in their natural state or after physical-chemical transformations to make them usable or else they are products of spent fuel reprocessing. These materials are listed in the *National Inventory* as their reuse could produce radioactive waste. They could also, in the long term, fall within the radioactive waste category if their recovery was not envisaged.

At the end of 2013, around **5,000 tHM* of fuel** were in use in nuclear power plants.

RADIOACTIVE MATERIALS ARE DIVIDED INTO THE FOLLOWING CATEGORIES:

Natural uranium **extracted from mines**

Uranium is a naturally-occurring radioactive metal found in rock in the form of an ore. Natural uranium extracted from mines is processed into a solid yellow concentrate known as *yellow cake*. There are currently no longer any uranium mines open in France; all the natural uranium used comes from abroad.

Enriched **uranium**

Enriched uranium is obtained by increasing the concentration of uranium-235 in natural uranium. It is used to make fuel for nuclear reactors.

Depleted **uranium**

Uranium which is depleted in uranium-235 is a residue obtained during the natural-uranium enrichment process. It is transformed into a solid, chemically stable, incombustible, insoluble and non-corrosive material, in the form of a black powder.

Recycled uranium **(from reprocessing)**

Recycled uranium, recovered during spent fuel reprocessing, can be used to make new fuels.

Fuels in use in **nuclear power plants** and **research reactors**

At all times, there are stocks of fuel being used in nuclear power plants and research reactors.

**Tonne of heavy metal: One tonne of uranium or plutonium contained in fuel before irradiation.*

Spent fuel **pending reprocessing**

Spent fuel is stored in cooling pools before undergoing reprocessing to recover uranium and plutonium. Some spent fuels are stored without reprocessing pending a future reuse.

Plutonium from **spent fuel after reprocessing**

Plutonium is a radioactive element, artificially generated by the operation of nuclear reactors. Like uranium, it can be recovered when spent fuel is reprocessed. It is then used in the fabrication of fuels such as MOX.

Materials from the **processing of rare earths**

The rare earths, metals found naturally in the Earth's crust, are extracted from ores such as monazite and used in numerous applications (electronic equipment, automotive catalytic convertors, etc.).

- The processing of these rare earths gives rise to a by-product, **thorium**, a radioactive metal which is currently stored pending a possible future use.
- The processing of these rare earths also produces chemical effluents that are then treated to be neutralised. **Suspended solids (SS)**, composed of 25% rare earth residues, are recovered and can be reused.

MANAGEMENT

Part of the materials from spent fuel reprocessing can be recycled to recover uranium and plutonium. These materials are stored in facilities suited to their characteristics, until they can be used or reused.

WHAT IF THESE MATERIALS WERE NOT REUSED?

The owners of these materials are required to develop a management method; this is for the possibility that these materials could not be reused and would thus fall into the

OWNERS

The main owners of nuclear materials are as follows:

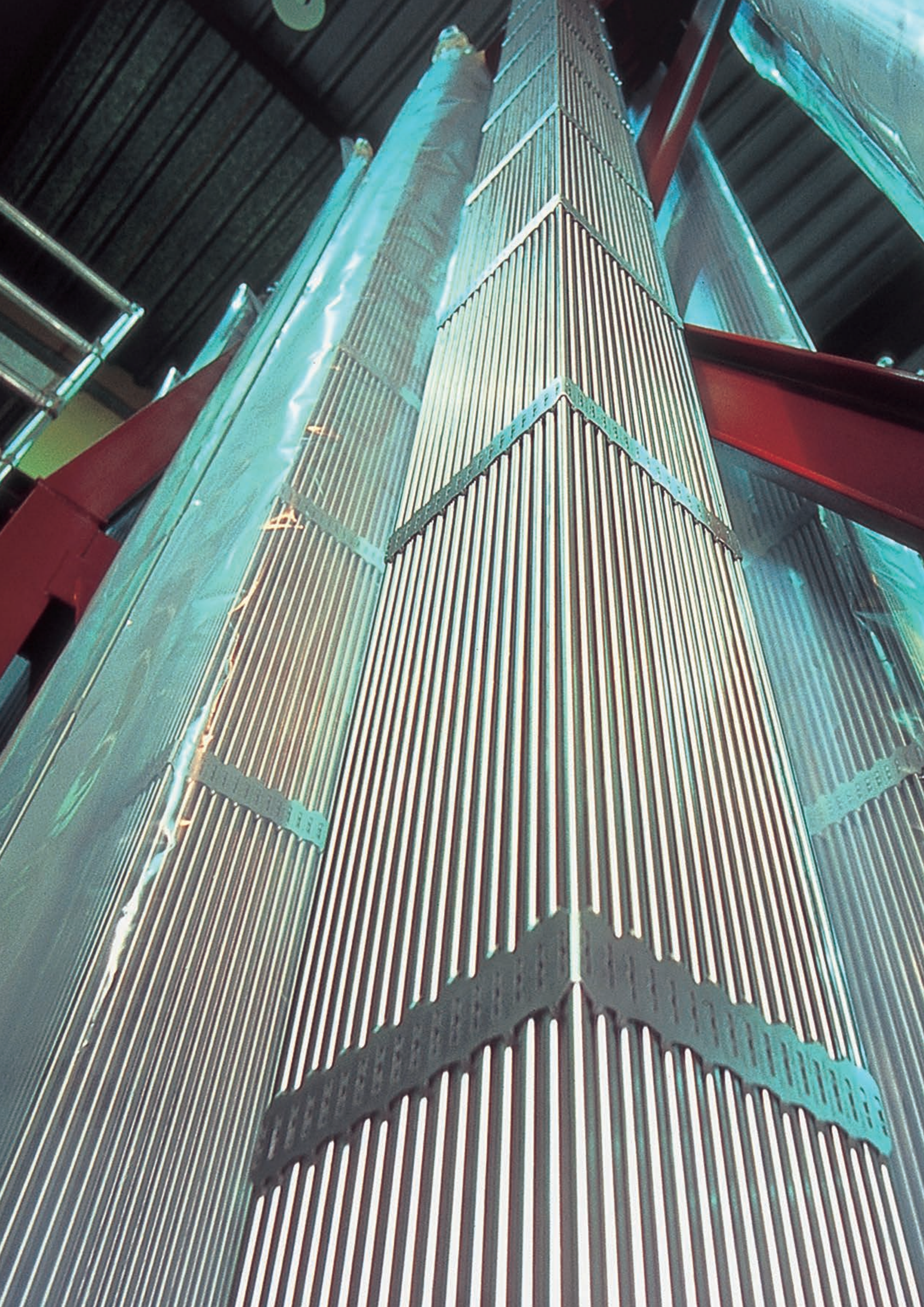
- AREVA is involved at all levels of the fuel cycle, except the use of nuclear fuels in power reactors. The fuel cycle includes the extraction of uranium and its concentration, conversion, enrichment, fabrication into fuel then the reprocessing of spent fuel;
- The CEA uses fuel for research purposes;
- EDF uses fuel to produce electricity;
- SOLVAY uses rare earth extracts from ores that also contain thorium;
- National defence owns nuclear materials for activities associated with nuclear deterrence and nuclear propulsion of various ships and submarines, along with the associated research.

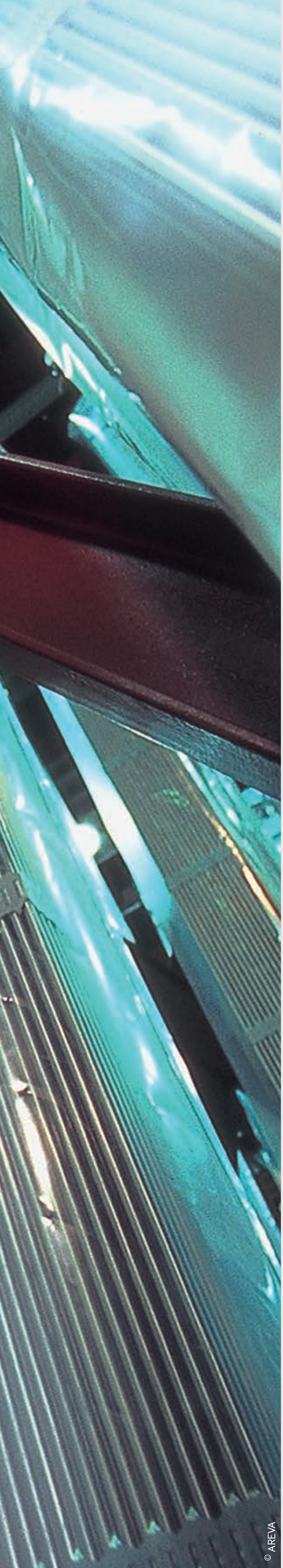
To a marginal degree, the healthcare industry owns nuclear materials (depleted uranium) used for radiation shielding.

Radioactive materials are broken down as follows:

Industry	Quantity (in tHM)*
Nuclear power	360,000
Research	300
Industries other than nuclear power	8,600
Healthcare	15
Defence	156 tons

** The quantities of radioactive materials are rounded to tonne of heavy metal.*





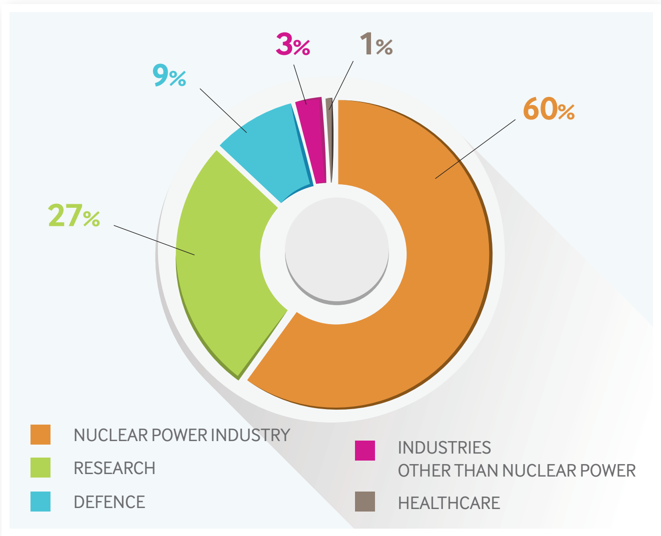
CHAPTER 2

WHAT ARE THE EXISTING AND FORECAST VOLUMES?

1. RADIOACTIVE WASTE ALREADY GENERATED

At the end of 2013, there were approximately 1,460,000 m³ of radioactive waste in France. Old waste managed according to "historical" methods *(see page 36)* is not included in the records presented here, as it will not be handled by Andra.

BREAKDOWN OF TOTAL WASTE VOLUME BY INDUSTRY



WASTE VOLUMES EXISTING AT THE END OF 2013

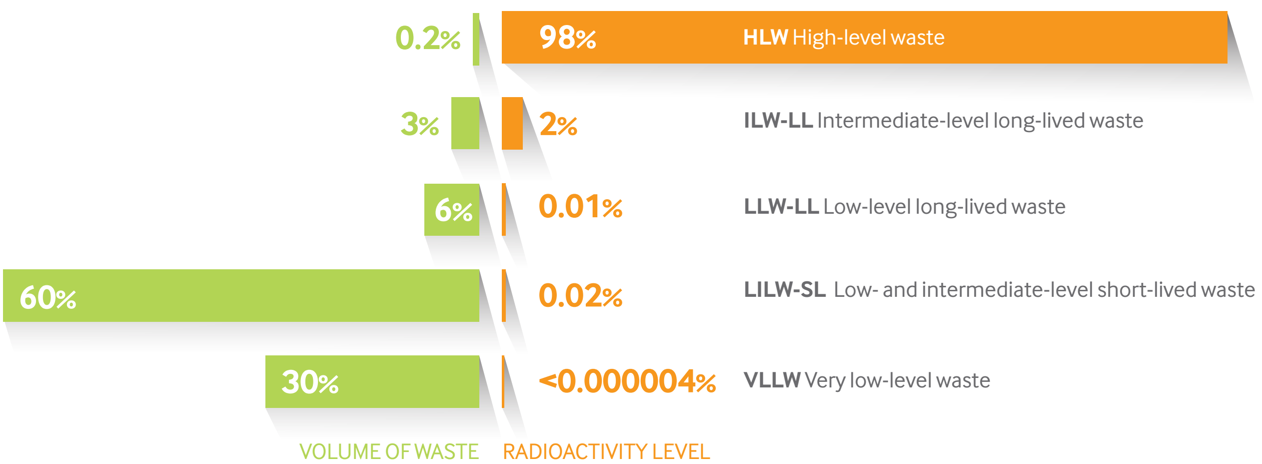
These volumes represent waste packaged in what are known as "primary" packages that can be managed in the disposal facilities. Additional conditioning is sometimes necessary before waste is taken into the management system, as in the case of deep geological disposal.

Category	Volume at the end of 2013
HLW	3,200
ILW-LL	44,000
LLW-LL	91,000
LILW-SL	880,000
VLLW	440,000
NSDR*	3,800
Total	**~1,460,000**

As disposed volume in m³

**Waste that has no specific disposal route represents a small portion (a little less than 0.3%) of the total volume of radioactive waste and is currently being studied to determine which management route it falls into. This waste is not included in the graph below.*

BREAKDOWN BY VOLUME AND RADIOACTIVITY LEVEL OF RADIOACTIVE WASTE PRESENT AT THE END OF 2013



CHANGES IN VOLUMES

The volumes of radioactive waste presented in the 2015 edition (end-2013 data) have changed relative to those presented in the 2012 edition (end-2010 data). These changes are due to the ongoing generation of waste during the three years separating the two editions of the *National inventory*, and also to:

- changes in the packaging assumptions for certain types of waste, which in certain cases results in an increased ILW-LL and LLW-LL package volume (but not an increase in the amount of radioactive waste they contain);
- consideration of sludge from washing certain uranium containers used on the Pierrelatte site, resulting in an increase in the volume of LLW-LL;
- optimisation of the treatments and conditioning for certain types of radioactive waste;
- additional characterisation of certain waste types, which resulted in their being moved to a more suitable category.

Category	2013/2010 deviation
HLW	500
ILW-LL	4,000
LLW-LL	4,500
LILW-SL	52,000
VLLW	77,000
NSDR*	200
Total	**~140,000**

As disposed volume in m^3

**Waste that has no specific disposal route represents a small portion (a little less than 0.3%) of the total volume of radioactive waste and is currently being studied to determine which management route it falls into.*

2. FORECAST STOCKS OF RADIOACTIVE WASTE

Regulations require holders of radioactive materials and waste to make production forecasts for the end of 2020 and 2030. Since 2014, waste holders must also provide final forecasts, i.e. forecasts for the end of facility operation, up to and including dismantling; they must also indicate the service life assumptions and dismantling scenarios used to establish these forecasts.

For the nuclear power industry, the key assumptions are*:

- **An average operating life of 50 years for all reactors;** this assumption reflects the strategic orientations of EDF relative to the longer operation of the fleet and does not pre-empt the decisions made by the ASN (French Nuclear Safety Authority) in the area of safety or any changes that may occur in French energy policy;
- **Start of reactor dismantling and production of graphite LLW-LL anticipated around 2025.** It should be noted that the dismantling of the fleet's first-generation facilities is underway with the production of short-lived waste (LILW-SL and VLLW), some of which has already been sent to Andra disposal facilities;
- **Reprocessing of all spent fuel,** in line with the current management policy; it is commonly assumed that current fuel reprocessing plants will operate for a time sufficient to carry out these operations. It is further assumed that materials separated will be reused in the current nuclear power fleet or in a future fleet;
- **A spent fuel reprocessing flow of around 1,000 tonnes per year.**

**The key assumptions of the scenario are based on the strategic vision of producers in 2013. These assumptions do not take into consideration possible future changes in response to the strategic orientations of EDF or regulatory modifications.*

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

CATEGORY	STOCKS AT END OF 2013	FORECASTS FOR END OF 2020	FORECASTS FOR 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

3. DISMANTLING WASTE

The nuclear power industry is relatively young, dating back to the early 1960s, so the main dismantling work on nuclear power plants and nuclear fuel cycle facilities is yet to come and will take place mostly after 2030.

The waste resulting from dismantling operations is of two types: conventional and radioactive. The distinction is made because basic nuclear installations have been divided according to zones, based on the history of the facility and the activities carried out there in the past.

- Waste from conventional waste zones is not radioactive and consequently does not need to be dealt with through specifically nuclear management solutions.

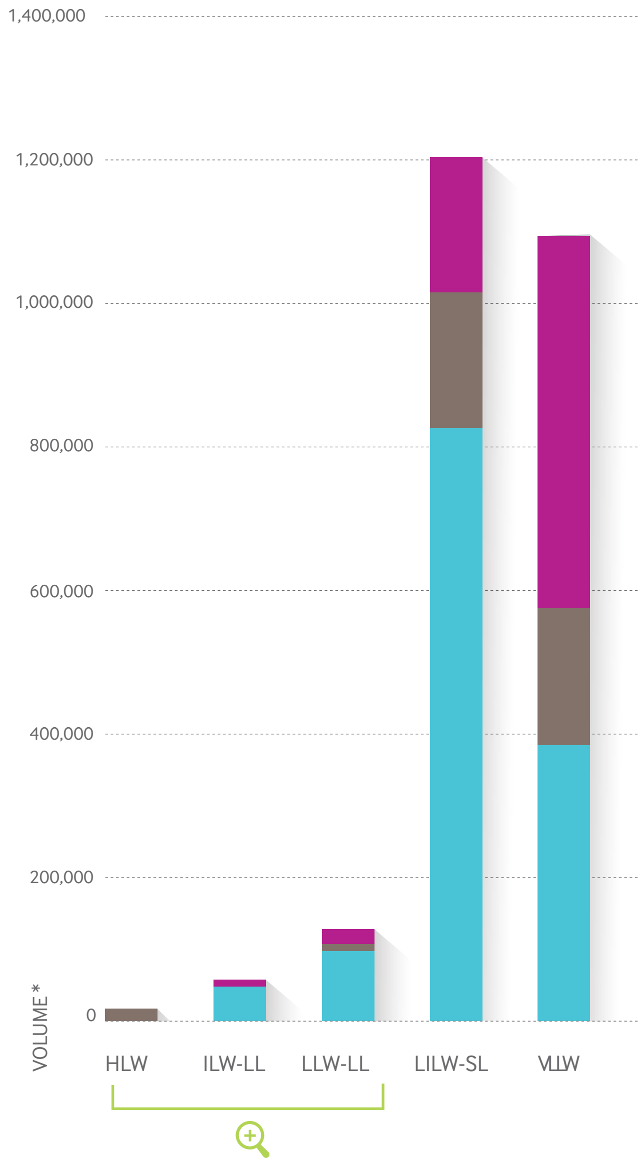
- Waste from zones potentially generating radioactive nuclear waste is all considered radioactive on principle, even if no radioactivity has been detected in it.

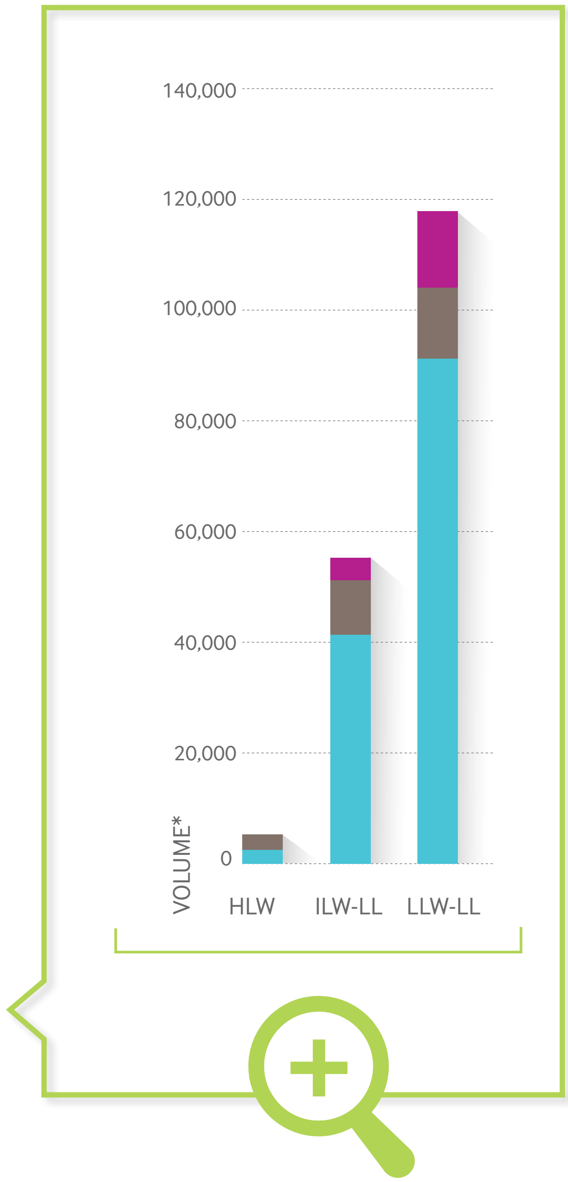
DISMANTLING WASTE

Dismantling a nuclear power plant produces an average of 80% "conventional" waste, such as rubble and other material, and 20% radioactive waste, the large majority of which is VLLW.

The facing graph shows the forecast waste quantities for the end of 2030 by category, and indicates the waste quantities from dismantling. Most radioactive waste resulting from the dismantling is in the VLLW category and, to a lesser degree, the LILW-SL category. In some special cases and according to the type of facility, dismantling waste may also belong to the ILW-LL category. Dismantling operations on first-generation, gas-cooled reactors will generate low-level long-lived waste.

FORECASTS OF WASTE QUANTITIES FOR THE END OF 2030





LEGENDS

- 2013 STOCK
- OPERATION PORTION AT END 2030
- DISMANTLING PORTION AT END 2030

As disposed volume in m³

4. PROSPECTIVE INVENTORY OF RADIOACTIVE WASTE

To reflect any changes in energy policy affecting the nuclear industry, the *National Inventory* also includes a prospective evaluation of waste and materials that will be generated by all authorised facilities from the end of 2013 until the end of their operating life, including dismantling. The evaluation is based on two energy scenarios that are purposely quite different (continuation of nuclear power production and discontinuation of nuclear power production). This does not pre-empt any changes to French energy policy. In both cases, the *National Inventory* covers only the waste produced by those facilities having obtained their construction permit by the end of 2013 (existing facilities plus the Flamanville EPR currently under construction).

TWO SCENARIOS

1 Nuclear power production continues

Scenario 1 entails continued operation of the nuclear power plant fleet and of spent fuel reprocessing, with an average operating life of 50 years for all current reactors and a maximum electricity production capacity for nuclear sources of 63.2 GWe. All spent fuel generated by the existing fleet is assumed to be reused in the future reactors that will replace current facilities.

2 Nuclear power production is discontinued

Scenario 2 entails discontinuing nuclear power production. It assumes progressive shutdown of facilities as they reach the end of their service lives (based on an average lifetime of 40 years). In this scenario, spent fuel reprocessing would be discontinued and the fuel would become waste that would be disposed of under the same conditions as HLW. This concerns all types of spent fuel (e.g. MOX) that are currently stored pending future reuse. The quantities of spent fuel to be considered represent a disposal package volume of around 89,000 m^3.

ESTIMATION OF FINAL WASTE PRODUCED IN THE TWO PROSPECTIVE 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		~7,000 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-SL (m^3)		1,900,000	1,800,000
VLLW (m^3)		2,200,000	2,100,000

The difference in HLW and ILW-LL waste volumes between the continuation and discontinuation scenarios is due to the differences in industrial strategy for spent fuel reprocessing and the different service lifetimes considered. The increase in LILW-SL and VLLW is due only to the difference in average service lifetimes considered in each of the scenarios.

NOTE

Spent fuel is currently not considered waste, and is therefore not packaged for disposal. Since the average volume of a fuel assembly is 0.19 m^3, these assemblies represent a volume of 12,000 m^3 before packaging. In 2012, Andra checked the feasibility of disposing of spent fuels as part of the Cigéo project. The container designs for this disposal represent a volume of around 89,000 m^3 (around 8 times the non-packaged volume).

5. RADIOACTIVE WASTE ALREADY GENERATED AND FORECAST STOCKS

The stocks of radioactive materials at the end of 2013, as well as production forecasts for the end of 2020 and 2030, are shown in the table below.

The 2020 and 2030 forecasts are for information only, since they depend on the management method each waste holder will choose according to the relevant economic conditions. The 2020 and 2030 production scenarios for nuclear fuel cycle materials are the same as those used for waste.

Storage of spent fuel in fuel cooling pool

RADIOACTIVE MATERIALS AT THE END OF 2013, 2020 AND 2030 (tHM)*

Categories	Stocks at the end of 2013	Forecasts for the end of 2020	Forecasts for the end of 2030
Natural uranium in all forms	319,000	356,000	436,000
Uranium from spent fuel reprocessing	27,000	34,000	44,000
Uranium oxide fuel from nuclear power reactors (UOX, ERU)	17,000	17,000	17,300
Plutonium and uranium mixed oxide fuel from nuclear power reactors (MOX, SuperPhénix, Phénix)	2,400	3,400	4,600
Research reactor fuels	75	75	77
Plutonium	52	33	39
Thorium	8,500	8,500	8,400
Suspended solids	5	3	0
Other materials	72	72	72

**Tonne of heavy metal.*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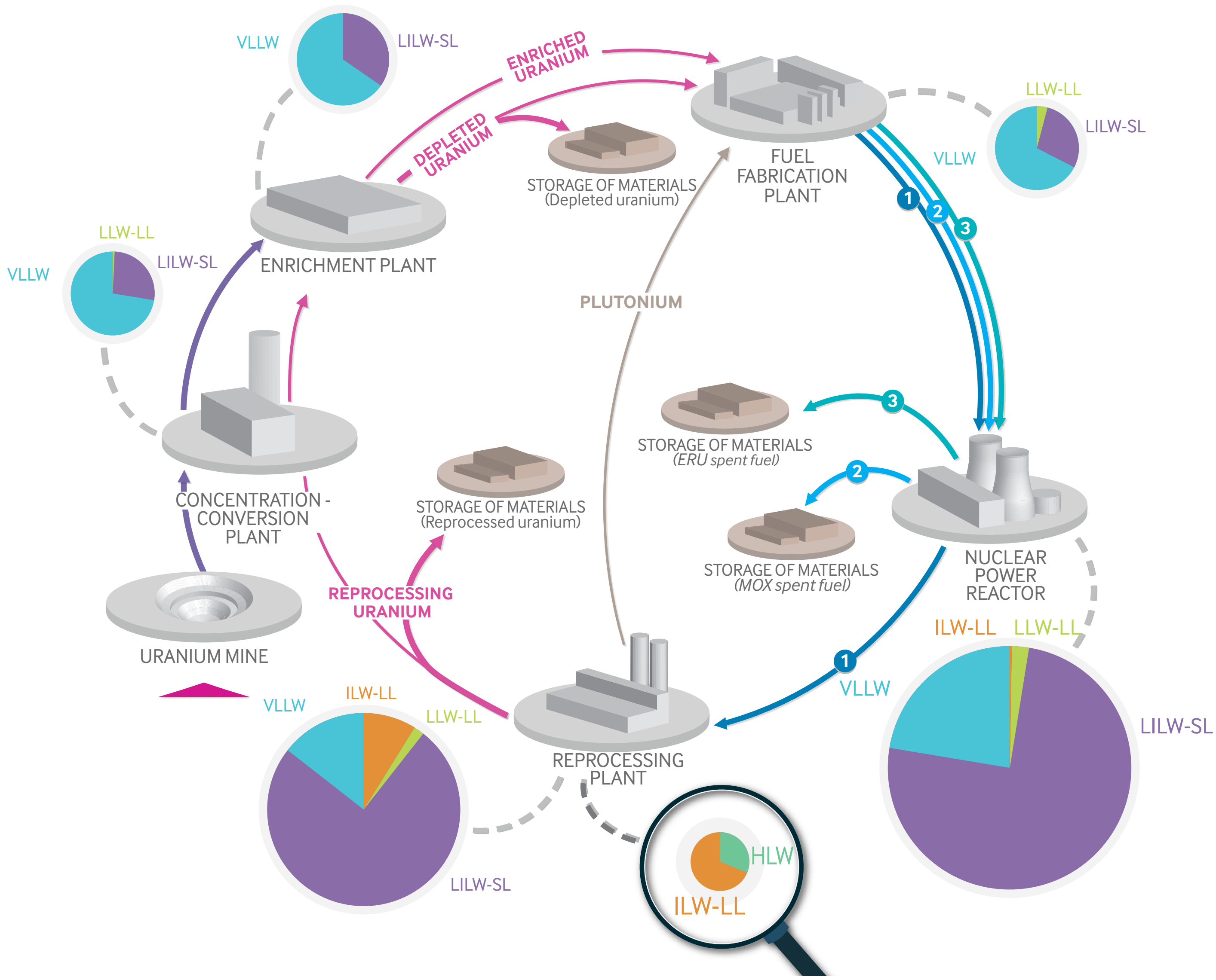
CHAPTER 3

WHAT HAPPENS TO RADIOACTIVE MATERIALS AND WASTE?

1. CURRENT MANAGEMENT OF RADIOACTIVE MATERIALS AND WASTE PRODUCED BY THE NUCLEAR POWER INDUSTRY



LEGENDS

1. Nuclear fuel made from natural enriched uranium oxide (UOX)
2. Plutonium and uranium mixed oxide fuel (MOX)
3. Nuclear fuel made from re-enriched uranium oxide from reprocessing (ERU)

- Operation and dismantling waste
- Waste from spent fuel reprocessing

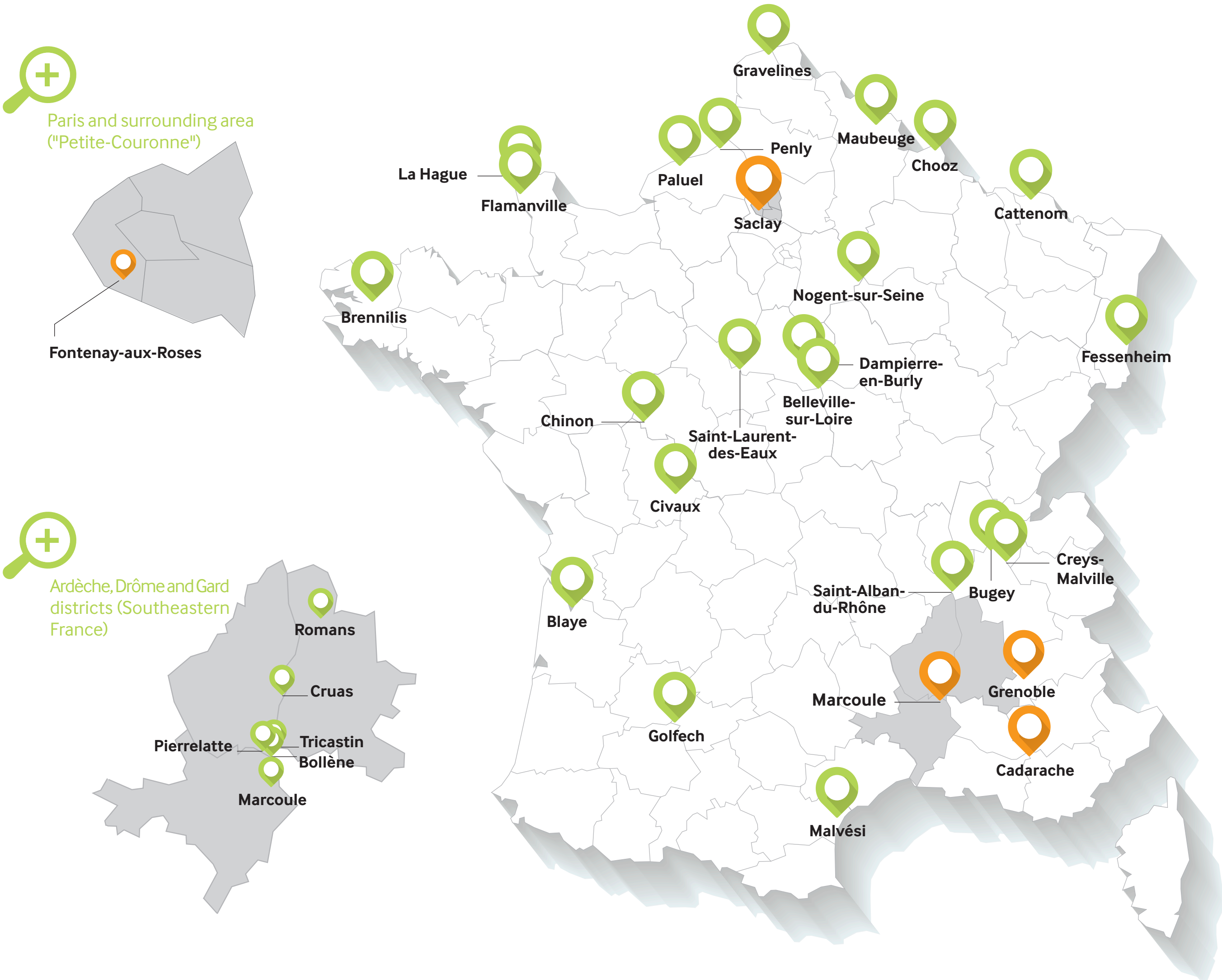
NOTE

Most of the waste produced by facility operation is short-lived waste. It is sent to the Aube industrial disposal facilities run by Andra (French National Radioactive Waste Management Agency). Intermediate level long-lived waste (ILW-LL) is stored at its production site.

Dismantling of all facilities also produces waste, most of which is very low level waste (VLLW).

Radioactive materials are currently reused, or stored until reuse is possible. Research is being conducted on a cycle with 4th generation fast breeder reactors, aimed at improving the recycling of materials, specifically MOX and ERU fuels as well as depleted uranium.

2. MAIN RADWASTE PRODUCING FACILITIES



LEGENDS

- Nuclear power industry
- Civil research facilities (CEA)

3. TREATMENT AND CONDITIONING OF PACKAGES

Radioactive waste is generated in raw form as a gas, liquid or solid. For management purposes, this waste must be conditioned, which entails producing "waste packages" that allow handling and ensure non-dispersal of radionuclides. Depending on the physical-chemical nature of the waste, conditioning may be preceded by treatment to arrive at waste characteristics that are suitable for long-term management, and to reduce volume and toxicity as much as possible.

The treatment, matrix and container are selected mainly based on the characteristics of the raw waste, especially its radiological characteristics.

For example, VLLW is simply placed in big bags or large containers without an immobilising matrix.

The most highly radioactive waste - fission products and minor actinide solutions from spent fuel reprocessing - is conditioned in a glass matrix.

Intermediate- or low-level waste must be immobilised in cement, polymer resin or bitumen matrices.

The waste is then placed in a suitable container to form a waste package.

There are eight main treatment and conditioning processes:

- compaction
- incineration
- melting
- encapsulation in polymer resins
- evaporation
- cementation
- vitrification
- bituminisation

©Andra

Disposal of a LILW-SL package in a cell at CSA

WASTE PACKAGE

A waste package generally comprises three elements:

- radioactive waste
- immobilisation material (glass, concrete, resin, bitumen)
- container (metal or concrete)

4. TRANSPORT

Around 800,000 transport operations involving radioactive substances are organised in France each year. In the large majority of cases, transport takes place by road, but also by air, train and sea. Transport for the nuclear power industry represents only a small part of these operations (15%). In 2014, there were 3,200 transport operations involving radioactive waste packages being sent to Andra's disposal facilities in the Aube.

Transport safety is based on three main principles. The first is to design packages whose robustness is aligned with the hazard rating of the radiological content. Packages are placed in transport containers that undergo various certification tests (free drop tests, compression tests, spray tests, puncture tests). Their design complies with strict safety rules set by the International Atomic Energy Agency (IAEA); in France, the application of these rules is monitored by the French Nuclear Safety Authority.
The second principle involves reliable transport operations. The regulations stipulate that the consignor is responsible for package safety throughout transport. The consignor characterises the transported material, conditions it in packaging that complies with regulatory requirements, ensures package labelling and prepares transport documents. The consignor also monitors loading and securing of packages in the vehicle. The transporter is responsible for aspects affecting proper performance of the transport operation: vehicle safety, driver training, marking, safety equipment, etc.
The third principle concerns preparation for emergency situations. Those in charge of transport must set up an organisation and all necessary means for controlling the consequences of an accident, should one occur. A specific emergency plan has been set up in each administrative region of France to define the organisation of emergency services in case of accident. Regular exercises are conducted as part of these plans, coordinated by the prefect.

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Arrival of containers of LILW-SL packages at the Brienne-le-Château train terminus

TRANSPORT OF RADIOACTIVE MATERIALS AND WASTE

The transport of radioactive materials and waste is subject to the following:
- Class 7 provisions of the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR),
- French hazardous materials transport regulation (RTMD).

The regulations mainly concern:
- package robustness,
- convoy reliability,
- efficiency of response in case of accident.

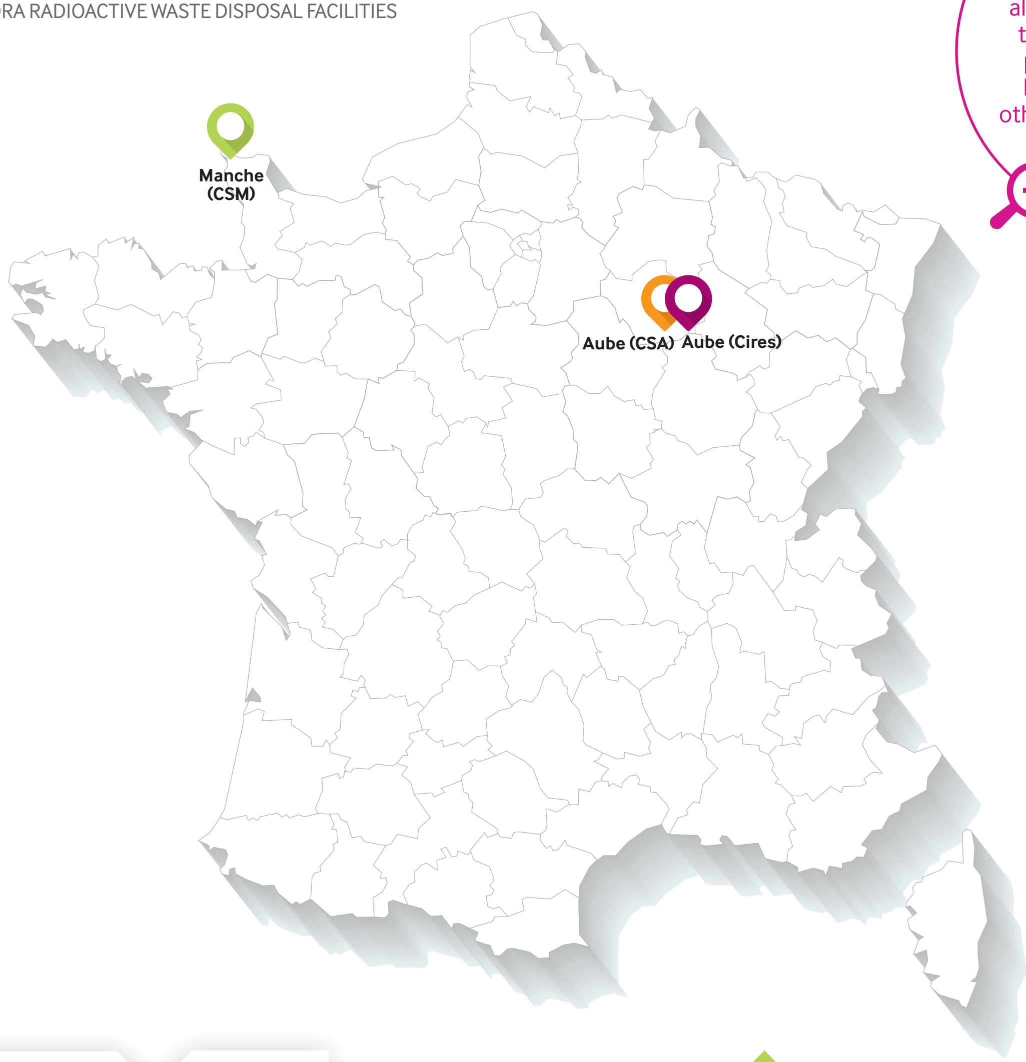
Domains	Examples of transport	Percentage of transported packages (in number)
Nuclear power industry	Transport associated with various steps of nuclear fuel cycle (conversion, enrichment, fabrication, use, processing, disposal).	15%
Technical inspection and research	Transport of lead detection equipment (used in building inspection) and gamma ray sources (industrial radiography) to locations of use; radioactive sources for research.	65%
Healthcare	Radiopharmaceutical products (e.g. for medical diagnostics) and radiotherapy sources supplied to hospitals. Many of these products have a very short lifetime.	20%

5. DISPOSAL OF VLLW AND LILW-SL RADIOACTIVE WASTE

In France, there are three surface disposal facilities operated and monitored by Andra. These facilities hold the large majority of waste generated each year in the country: very low-level waste (VLLW) and low- and intermediate-level short-lived waste (LILW-SL).

French disposal facilities already exist for **90%** of the radioactive waste produced each year. Disposal facilities for other waste are currently under study.

ANDRA RADIOACTIVE WASTE DISPOSAL FACILITIES



LEGENDS

- CSM radioactive waste disposal facility (Manche)
- CSA radioactive waste disposal facility (Aube)
- Cires radioactive waste management, interim storage and disposal facility (Aube)

WILL THE EXISTING DISPOSAL FACILITIES BE SUFFICIENT FOR FUTURE VOLUMES?

No, but before considering the creation of new disposal facilities, efforts will be made to reduce the volumes of waste to be disposed of at source (recycling, treatment, compaction, etc.). The possibility of extending the capacity of the existing facilities could also be examined.

1 CSM radioactive waste disposal facility in the Manche

The CSM facility (Manche, Northwestern France) opened in 1969. After 25 years of operation, the building was closed and capped with several layers of protective material, in particular for weatherproofing purposes.
Since the closure of the site in 1994, Andra carries out regular monitoring to detect any changes and monitor the impact on the environment. Andra also undertakes the works necessary to ensure the durability of the cap. This monitoring will last for at least 300 years.

527,225 m³ of waste are disposed of at the Manche disposal facility.

2 CSA radioactive waste disposal facility in the Aube for low- and intermediate-level short-lived waste (LILW-SL)

Benefitting from the expertise acquired over a quarter of a century at the CSM disposal facility, the CSA facility in the Aube has been receiving LILW-SL since 1992. It covers 95 hectares, of which 30 are reserved for the repository. The waste is disposed of on the surface in reinforced concrete structures 25 metres square and 8 metres high. Once they are filled, these structures are closed with a concrete slab and then sealed with an impermeable coat. At the end of operation, the structure will be covered with a clay cap in ordrer to ensure the confinement of the waste over the long term.
The CSA will be monitored for at least 300 years.

The Aube disposal facility was designed to hold **1 million m³** of waste. At the end of 2013, **280,000 m³** were already in disposal.

3 Cires (radioactive waste management, interim storage and disposal facility) in the Aube for very low-level waste (VLLW)

France made the decision to consider VLLW as radioactive waste and in 2003 opened a dedicated facility: Cires. Located in the Aube in Eastern France, Cires covers 45 hectares, of which 28.5 are reserved for the repository. Once conditioned, the batches of waste are identified and placed in cells 176 metres long by 25 metres wide, excavated in a clay layer to a depth of several metres. These cells are then closed and covered with a protective cap consisting mainly of sand, an impermeable membrane and clay. Since 2012, Cires has had two new activities: management and interim storage of waste not from the nuclear power industry.

This VLLW disposal facility was designed to hold **650,000 m³** of waste. At the end of 2013, it already contained **250,000 m³**.

FACILITIES UNDER SURVEILLANCE

Whether they are closed or in operation, the facilities are **regularly monitored** to check that their impact on the environment and nearby populations remains well below that of the naturally-occurring radioactivity.

On 31 December 2013, 73% of the volume of radioactive waste generated (except for waste managed by historical methods) was definitively disposed of. The remaining waste is temporarily stored:

- awaiting disposal in existing disposal facilities;
- awaiting the creation of a suitable disposal facility.

6. DISPOSAL PROJECTS FOR HLW, ILW-LL AND LLW-LL

Of the radioactive waste produced in France, less than 10% has a level of radioactivity or a lifetime that precludes their disposal at the surface. Most of this waste is HLW, ILW-LL and LLW-LL. Andra is currently conducting studies (Cigéo and LLW-LL projects) to design disposal facilities for this waste that would isolate it for very long periods of time. Such facilities must be built several tens of metres below the surface, or even hundreds of metres, in rock layers that serve as natural barriers over very long stretches of time.

LLW-LL PROJECT

Pursuant to the French Law of 28 June 2006, the French government asked Andra to develop disposal solutions for low-level long-lived waste (LLW-LL). A specific solution is necessary for this waste, which cannot be disposed of at the surface due to its lifetime, but for which a repository at a significant depth (Cigéo project) is not justified due to the hazard level of the waste.
After initiatives in 2008-2009 that were unsuccessful, in 2012 Andra submitted a report to the government in which it redefined its positioning, based on the recommendations of the HCTISN (French high committee for transparency and information on nuclear safety).

The government gave its approval and in 2013-2015, Andra carried out geological investigations near its existing disposal facilities in the Aube, in cooperation with the Soulaines community of municipalities. Andra also initiated discussions with sites where a nuclear facility is already located and areas where municipalities were candidates in 2008.
In parallel, waste producers prepared a more detailed radiological inventory of their waste, and examined the possibilities for sorting/treating this waste. Midway through 2015, Andra submitted to the government a report presenting the results of the geological investigations, a description of the concerned waste, a summary of safety issues and disposal concepts, and the studies remaining to be performed to better define the project.

Borehole for geological investigations in view of finding a disposal site for LLW-LL

CIGÉO PROJECT

After 15 years of research, the French Law of 28 June 2006 tasked Andra with studying the design and location of a reversible disposal facility at a depth of 500 m for HLW and ILW-LL; this led to the Cigéo project, with sites in Northeastern France (Meuse and Haute-Marne).
The Cigéo industrial design work began in 2012 with a feasibility phase, making it possible to define an overall architecture of the industrial project, presented during a public debate in 2013.

The provisional calendar for Cigéo is as follows:

- 2015, submission of a proposal for an operational master plan to the government and a safety options package and a retrievability technical options package to the French Nuclear Safety Authority with a view to the examination of the Cigéo construction licence application;

- 2017, end of basic design phase with the submission of the construction license application by Andra.

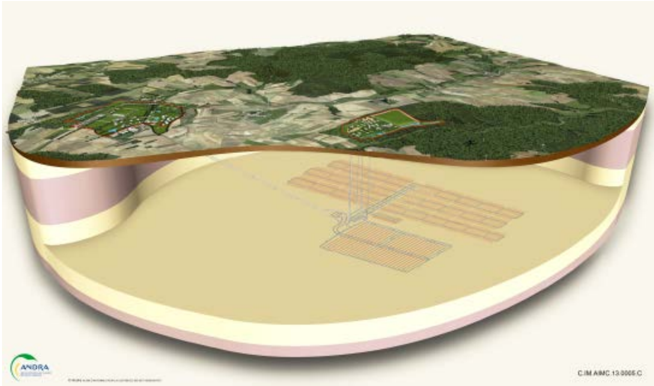
If the necessary licenses are granted:

- 2020, start of repository construction;

- 2025, facility start-up with a pilot industrial phase.

CLAY

In France, studies have examined the disposal of HLW and ILW-LL in **argillaceous rocks**, which have the particular property of **delaying and limiting the movement of the radionuclides contained in the waste** over very long periods.



Cigéo disposal project for HLW and ILW-LL

To date, **60%** of ILW-LL and **30%** of HLW intended for Cigéo have already been generated

WHERE IS THE WASTE?

Pending the construction of disposal facilities suitable for the hazard levels and lifetimes involved, radioactive waste is stored where it was generated.

7. FORMER MANAGEMENT METHODS

Certain radioactive waste products were managed in accordance with methods that are currently no longer in use; this waste will not be handled in the Andra disposal facilities. For this reason, it is not included in records presenting volumes of waste, but is nonetheless listed in the *National Inventory*.

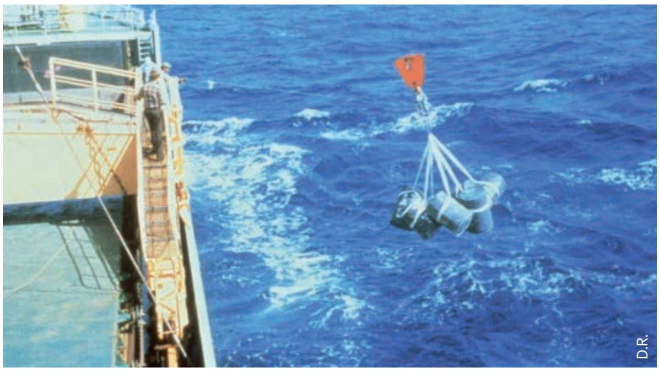
SEA DUMPING

Starting in the late 1940s and for some 30 years thereafter, many countries dumped radioactive waste into the sea. This was first performed at shallow depths, generally in the territorial waters of the countries dumping the waste. Later, sea dumping was coordinated by international bodies and carried out at great depths in international waters.

The dumped waste took several forms:

- liquid waste, directly discharged into the sea or placed in containers;
- unconditioned solid waste or, in most cases, solid waste packaged in metal drums after incorporation in concrete or bitumen.

France participated in two campaigns, in 1967 and 1969, during which it dumped 14,200 tonnes of radioactive waste into the Atlantic. A total of 3,200 tonnes of waste from the French nuclear testing programme in the Pacific were also dumped between 1967 and 1982. France abandoned this practice in 1982.



Sea dumping campaign for radioactive waste

Sea dumping, based on the assumption that waste would be significantly diluted in the ocean, was at one time considered as the most appropriate disposal route. France abandoned this practice in 1982.

DISPOSAL OF URANIUM ORE PROCESSING RESIDUES ON FORMER MINING SITES

Between 1948 and 2001, exploration and mining for uranium took place on 250 sites in France.

The ore processing operations to recover the uranium generated radioactive residues (blocks, sand, sludge). These residues constitute long-lived radioactive waste with a radioactivity level comparable to VLLW.

When uranium mining ended in France, an estimated 50 million tonnes of residues were disposed of on 20 of these former mine sites. They are monitored by AREVA, under the supervision of the relevant authorities.

The ore processing plants have all been decommissioned and dismantled.

OTHER “LEGACY” SITUATIONS

In France, there are over 100 "legacy" disposal facilities that do not come under Andra's responsibility:

- Disposal of waste with high natural radioactivity. This waste is generated by the transformation of raw materials that naturally contain radionuclides, but are not used for their radioactive properties: waste from fertiliser, residues from aluminium oxide production and fly ash from thermal power plants;
- *In situ* disposal: disposal sites near nuclear installations or plants, usually consisting of hillocks, backfill or ponds;
- In the past, conventional waste disposal facilities would regularly or occasionally receive waste with low levels of radioactivity, on the order of a few becquerels per gram.

GLOSSARY
& ABBREVIATIONS

	TERMS	DEFINITIONS
B	BECQUEREL (Bq)	Unit of measurement for radioactivity. One becquerel corresponds to the decay of one atom per second.
C	CSA	Disposal facility operated by Andra in the Aube (Eastern France) for low- and intermediate-level short-lived waste (LILW-SL).
	CIGÉO	Geological disposal facility.
	CIRES	Radioactive waste management, interim storage and disposal facility operated by Andra in the Aube (Eastern France) for very low-level waste (VLLW).
	CONDITIONING	The immobilisation of waste in a container, using a matrix material where necessary.
D	DISPOSAL	The placement of radioactive waste in a specially designed facility for potentially permanent storage.
E	ERU FUELS	Enriched reprocessed uranium fuels.
F	FNR FUELS	For the Phénix and Superphénix fast neutron reactors (FNR). These are MOX type fuels.
L	LONG-LIVED WASTE	Radioactive waste containing a significant quantity of long-lived radionuclides, i.e. those with a half-life of more than 31 years.
M	MOX FUELS	Mixed uranium oxide and plutonium oxide fuels.
P	PACKAGE	Conditioned and packaged radioactive waste.
R	RADIOACTIVE HALF-LIFE	The time it takes for half of the quantity of a single radionuclide to undergo natural decay. The radioactivity of a pure sample of a single isotope would then be halved. After 10 such periods, the radioactivity would be divided by a factor of 1,000.
	RADIOACTIVE SOURCE	A device, radioactive substance or facility that emits ionising radiation or radioactive substances.
	RADIONUCLIDES	Unstable isotopes that undergo radioactive decay and emit radiation, which is the origin of the phenomenon of radioactivity.
S	SHORT-LIVED WASTE	Radioactive waste whose radioactivity mainly comes from short-lived radionuclides, i.e. those with a half-life of less than or equal to 31 years. This waste may also contain a limited quantity of long-lived radionuclides.
	SS	Suspended solids, residues from the processing of rare earths containing thorium.
	STORAGE	The temporary placement of radioactive matter or waste in a specially designed facility, pending subsequent retrieval.
T	TONNE OF HEAVY METAL (tHM)	One tonne of uranium or plutonium contained in fuel before irradiation.
	TREATMENT	All mechanical, physical or chemical operations that aim to modify the characteristics of waste.
U	UOX FUELS	Uranium oxide fuels.

Find the National Inventory
of Radioactive Waste and Materials on-line at

www.inventaire.andra.fr

A website of reference
that allows the readers
to familiarize themselves
with the radioactive waste
and its location.

ANDRA

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