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National Inventory of Radioactive Materials and Waste

Synthesis Report

ANDRA
La maîtrise des déchets radioactifs

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foreword

We are pleased to present the third edition of the National Inventory of Radioactive Materials and Waste, which is a reflection of Andra's long-term commitment to its inventory-related activities. These activities receive financial backing from the French Ministry of Ecology, Energy, Sustainable Development and Territorial Planning. The National Inventory is a cornerstone in the management of these materials and waste in that it provides input for the French National Radioactive Materials and Waste Management Plan (PNGMDR), soon to be reviewed by the Government.

Andra has opted for the same four-volume structure as that adopted for the 2004 and 2006 Inventories: Synthesis Report, Summary Report, Catalogue describing the families and Geographical Inventory, together with a CD-ROM. Readers have expressed their preference for this presentation which offers them a great deal of information in an easily accessible format, whatever their background or motives for reading the Inventory. This presentation also considerably simplifies comparison with other editions of the Inventory.

With an eye to efficiency and sustainable development, Andra now offers the producers and holders of radioactive materials and waste an online declaration tool and ready-completed declaration forms. This saves paper and time and reduces CO_2 emissions - for everyone's benefit.

The National Inventory provides a snapshot of the stocks of radioactive materials and waste as at 31 December 2007. In addition, it includes forecasts of these stocks for 2020 and 2030, as well as a statement of "committed" waste at the end of life of existing nuclear facilities and those licensed for construction, based on industrial forecasts. Some significant changes compared with the 2006 National Inventory will have caught the attentive reader's eye: first, conditioning and disposal solutions for some categories of waste have been reviewed in light of new findings, or in accordance with guidelines defined in the PNGMDR and, second, the number of committed facilities has grown, especially now that the Flamanville EPR has been licensed for construction.

Estimations of waste stocks in 2030, or at the end of life of existing facilities, can only be based on assumptions as to the future of facilities and the French Government's energy policy in the long term. These are matters for plant operators and the public authorities to decide. This part of the National Inventory addresses issues which Andra thought should be made accessible to as broad a public as possible, even if they are of a more technical nature. The assessments made should be seen as estimations that are dependent on future decisions and policies.

Although "small-scale nuclear activities" waste producers (hospitals, medium-sized research centres and industries making occasional use of radioactive objects, etc.) only account for a fraction of waste, they represent most of the sites concerned. The list of these producers and the related data have been updated and supplemented where necessary. The additional data included should not, however, make the reader lose sight of the fact that the National Inventory is only published every three years. Its approach is therefore macroscopic and cannot reflect variations in the activities of these producers.

Progress has been made in the treatment of sites contaminated by radioactivity and the National Inventory takes into account the recommendation made by the French High Committee on Transparency and Information on Nuclear Safety to standardise information on legacy waste disposal sites. The National Inventory lists 23 such legacy waste sites, with a clearer classification and fuller details than in the 2006 edition. Besides the record sheets, a specific section on this subject has been added to Subchapter 3.1 of this Synthesis Report.
Other improvements or supplementary information have been included to take into account Government requests, suggestions made by the National Inventory Steering Committee or readers, or simply added at Andra's own initiative. For example: the section on radioactive materials has been expanded; the distribution of waste by owner is more finely detailed; foreign waste in France on a temporary basis is presented for each country concerned; a new section is included, showing the capacity of existing storage sites for French waste pending the opening of two future disposal facilities - an LLW-LL repository to be opened in 2019 and an HLW and ILW-LL repository scheduled for 2025. Lastly, an appendix has been added for legacy waste dumped in the Atlantic or in the Channel and for waste from nuclear tests in the Pacific.

The purpose of the National Inventory and the responsibilities and role of the various parties involved in radioactive waste management have also been explained for information. Bibliographical references are included for further reading.

More improvements in both the form and content of the report will be possible in future editions. Feedback from readers provides us with a unique opportunity to add to the Inventory and make it useful for as many people as possible, so comments are always welcome.

We hope you enjoy reading this third edition.

F.M Gonnot

Dupuis

François-Michel Gonnot
Chairman of Andra

Marie-Claude Dupuis
Chief Executive Officer of Andra

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history of the National Inventory

Familiarity with radioactive material and waste is essential if it is to be managed properly. That implies having the fullest and most comprehensive view of its nature and the quantities involved.

Andra, the French National Radioactive Waste Management Agency, makes a constant and ongoing effort to achieve this.

The Act of 30 December 1991 entrusted Andra with the task of making an inventory of the type, condition and location of all radioactive waste present in France. Through its painstaking efforts over the years to collate and cross-check data, the Andra Observatory has built up a high-quality database on existing waste and its geographical location. Andra published an annual report on this topic for over a decade. The last edition, entitled "*Où sont les déchets radioactifs en France?*" [Where is the radioactive waste in France?], dates back to 2002.

Each of these reports presented all the available data on radioactive waste according to location. It was therefore a primarily geographical approach. The Observatory's task grew from year to year, as it attempted to account for an assortment of waste products at the limits of the "classical" nuclear industry. This has led to the compilation of a vast wealth of data.

These earlier reports were nonetheless limited in a number of ways. They simply listed existing waste without including any predictions on future waste. As they were not intended for accounting purposes, they did not provide a quantitative overview by waste category or activity sector. Lastly, they only accounted for radioactive waste, overlooking radioactive materials, i.e. radioactive substances planned or intended for future use.

These limitations were emphasised in 1998 by the National Review Board (CNE), which was created by the Act of 30 December 1991 to track progress in research into high-level or long-lived radioactive waste management. In its report, the Board recommended making a realistic inventory of existing waste by category, then updating it regularly and making forecasts concerning these substances, covering the broadest spectrum possible.

In 1999, the French Government acknowledged these recommendations by entrusting Yves Le Bars, Chairman of Andra, with the task of suggesting ways to enhance the reliability of the radioactive waste inventory and, in particular, to allow extrapolations based on medium- and long-term forecasts.

The Chairman submitted his report, entitled "*Rapport de la mission sur la méthodologie d'inventaire des déchets radioactifs"* [Report on Radioactive Waste Inventory Methodology] to the Government in 2000. He recommended carrying out a national inventory of existing and future radioactive waste to serve as a reference document for all stakeholders and the public at large, and defined the methodological requirements to achieve this. The report particularly stressed the accounting and forecasting tasks to be carried out, with a clear presentation of the assumptions on which the various forecasts were based. It also stressed the need to include radioactive material in this Inventory. Lastly, it emphasised the need to continue the work carried out by the Observatory, an invaluable tool for Government departments, elected representatives and the general public.

On the basis of this report, the Government took the decision in 2001 to assign to Andra the task of preparing and publishing a National Inventory of Radioactive Materials and Waste.

The following year, a Steering Committee, chaired by Andra, was set up to oversee work on the Inventory. The Committee was made up of representatives from the Ministries of Energy and the Environment, the French Nuclear Safety Authority (ASN), waste producers in the nuclear power and other sectors and, in an observer capacity, representatives of the National Review Board (CNE) and the Parliamentary Office for the Evaluation of Scientific and Technology Choices (OPECST).

The year 2004 saw the publication of the first edition of the National Inventory. The second edition, an update of the first, appeared in 2006.

Andra's responsibility for informing the public of the nature and location of radioactive waste, already defined in the Act of 30 December 1991, was confirmed by the Act of 28 June 2006, which stated that the Agency should establish, update every three years and publish the Inventory of Radioactive Material and Waste existing in France, as well as its location on the national territory, with the waste defined under Article L542-2-1[1] listed by country of origin.

As of the 2009 edition, the National Inventory provides input to the Radioactive Materials and Waste Management Plan (PNGMDR). The Plan is prepared and updated every three years by the Government and sets out all the activities concerning French policy relating to radioactive waste management and associated research and development work.

The 2009 edition of the National Inventory is broader in scope than its predecessors. For example, it includes information on storage facilities for waste awaiting a definitive management solution, as well as the information found in the 2004 and 2006 editions on radioactive material and waste. The content of some chapters has also been augmented (e.g. radioactive materials, waste dumped at sea, legacy waste disposal sites, etc.). The declarations made by waste producers and holders are now subject to regulations and obligations; these are defined in a Council of State decree and two ministerial orders.

The National Inventory sets out to promote a transparent waste management system that sets a standard. It is an invaluable instrument in exchanges between the various parties involved and reaches out to the widest possible audience, as illustrated by feedback from the readers of previous editions.

1 of the Environmental Code.

1

radioactive waste

definition of radioactive waste

1.1

Article L 541-1 of the Environmental Code states that "For the purposes of this Chapter, waste is defined as any residue of a process of production, transformation or use, any substance, material, product or more generally any movable goods abandoned or destined to be abandoned by its holder." It goes on to add that ultimate waste is defined as "waste, either resulting or not from the treatment of waste, which is not likely to be treated under the technical and economic conditions of the moment, notably by the extraction of the reusable part or by the reduction of its pollutant or hazardous character."
Article L542-1-1 of the same code, amended by the Planning Act of 28 June 2006 on the sustainable management of radioactive material and waste [I], stipulates that radioactive waste refers to radioactive substances for which no subsequent use is planned or intended, and defines a radioactive substance as any substance containing natural or artificial radionuclides where the activity or concentration justifies radiological protection monitoring. In other words, waste must be considered radioactive if it is liable, under certain conditions, to expose one or more human beings to radiation levels that cannot be overlooked from the health and safety point of view.

This definition raises two questions:

What exposure conditions should be considered?

During the lifetime of a waste product, some people may be exposed to its radiation in a variety of situations: for example, workers called on to handle it on industrial sites, the transporters who drive it to its disposal site and one-off cases of members of the public coming into contact with it.
Regulations call for special studies on waste for which the radioactivity classification is not obvious (for example, acceptance of waste exhibiting naturally-occurring radioactivity in hazardous or non-hazardous waste disposal facilities). Such studies should provide an exhaustive list of possible modes of exposure to the radiation emitted by this waste and calculate the committed dose - i.e. the effect on the body - expressed in sieverts (Sv).

[I] Planning Act 2006-739 of 28 June 2006 on the sustainable management of radioactive material and waste.

From what threshold is an effect no longer considered negligible from the radiation protection standpoint?

There is no simple, all-round answer to this question. The effects of low doses are hard to assess and are much debated in the scientific community. Within the context of the above-mentioned studies, the authorities recommend that this impact should be minimised. It should be less than 1 mSv (millisievert) per year and per person in the case of contaminated waste. For the sake of comparison, the average dose due to naturally-occurring radioactivity is 2.4 mSv per year and per person in France (UNSCEAR Report 2000, Sources and effects of ionising radiation).

It should be pointed out that France applies the precautionary principle on a routine basis to all waste involving man-made radioactivity and generated by the nuclear industry. Facilities such as reactors, laboratories, fuel processing plants and so on are accordingly divided into what are known as *nuclear and non-nuclear areas*. *Nuclear* areas produce waste which is liable to be contaminated by radioactivity.

The above considerations demonstrate that radioactive waste needs to be defined on a case-by-case basis for the lowest levels of radioactivity and that this definition cannot be boiled down to a single criterion.

It should also be borne in mind that most substances are naturally radioactive, albeit at very low levels - so low as to be impossible to measure in some cases - and that a great deal of everyday waste emits radiation, though not enough to be considered as radioactive waste.

Some countries have defined clearance levels[1], which are expressed in units of radioactivity by unit mass, although no international consensus has been reached on the matter. European Commission recommendation RP 122 gives suggested clearance levels, for information only, for both naturally-occurring and man-made radionuclides.

Council Directive 96/29/EURATOM of 13 May 1996 lays down exemption - not clearance - levels, below which human activities (referred to as practices) involving radioactive sources are not required to be reported or authorised. The levels defined in the Directive are regulatory *de facto* and have been transposed into French law under Article R 1333-18 of the French Public Health Code.

Some other points need to be grasped if we are to understand clearly what is meant by "radioactive waste".

Radioactive waste needs to be defined on a case-by-case basis for the lowest levels of radioactivity; this definition cannot be boiled down to a single criterion.

The notion of ultimate waste

The Act of 28 June 2006 defines ultimate radioactive waste as waste which is not likely to be treated under the technical and economic conditions of the moment, notably by the extraction of the reusable part or by the reduction of its pollutant or hazardous character.

1 Reminder: "clearance" means the automatic removal from the system set up by the responsible authorities, of radioactive waste resulting from authorised practices, with no need for any specific authorisation or subsequent control, on condition that the activity level of this waste is below a defined threshold.

Radioactive material: spent nuclear fuel and other radioactive materials (uranium, plutonium, etc.)

These substances have recycling potential. Consequently, neither their holders nor the public authorities consider them as waste. Article L542-1-1 of the French Environmental Code, amended by the Planning Act of 28 June 2006, defines radioactive material as a radioactive substance for which subsequent use is planned or intended, if necessary, after treatment.
Materials awaiting recycling remain in storage. In some cases, processing such materials for recycling purposes can generate waste.

Sites contaminated by radioactivity

Any cleanup operations carried out on contaminated sites are liable to produce waste. Chapter 5 of this document discusses these sites. The sites it mentions are "definite" contaminated sites, in other words, sites recognised as such by the authorities. Their inclusion in this chapter does not automatically imply that cleanup operations will be performed there. That is a matter for the authorities or owners to decide, depending on the estimated risk level and the intended use of the site.

Liquid or gaseous releases to the environment

Liquid or gaseous releases do not fall within the scope of the National Inventory. Information on actual releases from various nuclear facilities is available in the vicinity of the sites or in the brochures published by facility operators.

France makes a distinction between liquid or gaseous releases and solid waste or waste intended for solidification. Liquid or gaseous releases are generally dispersed to the environment rapidly. They do not fall within the scope of the National Inventory. Specific regulations, set out in **Decree 2007-1557 of 2 November 2007 on basic nuclear installations and the control of radioactive material transport from the nuclear safety viewpoint** , stipulates that radioactive and non-radioactive liquid and gaseous releases from basic nuclear installations are subject to authorisation, following a public enquiry, if they are liable to be a source of pollution. Permitted release levels are defined for each installation in government orders and can be consulted by the public. Information on actual releases from various nuclear facilities and on environmental monitoring programmes around these facilities is available in the vicinity of the sites concerned, or in the brochures published by facility operators. The ASN, the French Nuclear Safety Authority, examines release permit applications and provides regular summaries on them that can be consulted on its official website at www.asn.fr.
The French National Radioactivity Measurement Network (www. mesure-radioactivite.fr), as defined in the Order of 8 July 2008 (approving ASN decision 2008-DC-0099) keeps all the data gathered available for consultation by the public, together with a synthesis report on the radiological state of the environment.
Environmental defence groups also perform measurements around certain sites. The subject is thus widely covered elsewhere and the information is available to the public.

classification
of radioactive waste and the related management solutions

1.2

There are many characteristics that distinguish one type of waste from another, such as its physical and chemical nature and the level and type of radioactivity. Each type of waste calls for the implementation or development of specific treatment and management procedures, compatible with the hazard it presents and its development over time. Classification is a necessity.

Radioactive waste classification in France is based mainly on two parameters, the radiation level[2] and the radioactive half-life of the radionuclides contained in the waste. Half-life expresses the time it takes for the initial activity of a radionuclide to be halved. Other parameters are concerned by waste classification depending on the management solution.

The following can be distinguished:

- waste in which the radionuclides have a very short half-life (less than 100 days);
- waste in which the main radionuclides have a short half-life (less than or equal to 31 years);
- waste in which the main radionuclides have a long half-life (more than 31 years).

Radionuclides with a very short half-life are particularly used in medicine for diagnostic purposes. Their activity level, regardless of the initial level, drops to very low after a short time (equivalent to a few half-lives). The waste in question is then disposed of using conventional management solutions.

It is generally considered that as the initial activity levels involved are low or intermediate, short-lived waste no longer needs to be classified as hazardous after 300 years at the most.

In France, radioactive waste is divided into the following categories:

- high-level waste (HLW);
- intermediate-level, long-lived waste (ILW-LL);
- low-level, long-lived waste (LLW-LL);
- low- and intermediate-level, short-lived waste (LILW-SL);
- very-low-level waste (VLLW);
- very-short-lived waste (VSLW).

One important point to bear in mind is that in this classification system, the category reflects not the activity level or half-life of the waste concerned, but its management solution. In most cases, the radiological characteristics of the waste are those defined in the category to which the waste belongs. The characteristics (e.g. chemical composition) of some waste, however, may impose a different management solution. In such cases, the waste is assigned to the category concerned by this management solution. Several examples of this are given in Chapter III.

2 There are three types of radiation: alpha, beta and gamma. Note that alpha radiation is made up of helium nucleii; beta radiation of electrons or sometimes positrons; gamma radiation of high-energy photons. They exhibit different ranges and levels of toxicity.

Table 1.1 gives a schematic representation of the French radioactive waste classification system. For each category of waste, it shows the existing or considered long-term management solution. This solution can be either an existing disposal facility[3] or one planned for the future. The various management solutions are described in greater detail in Subchapter 1.4 and Appendix 3. Storage facilities, which are facilities designed to accommodate radioactive waste on a temporary basis, are not included in the table. This classification is now the French standard system. Older terminology may still be found, however, such as "A waste" for LILW-SL, "B waste" for ILW-LL, or "C waste" for HLW.

Table 1.1: Classification of radioactive waste by management solution

Activity \ Half-life	Very short lifetime Half-life < 100 days	Short lifetime Half-life ≤ 31 years [1]	Long lifetime Half-life > 31 years [1]
Very low level	Stored to allow radioactive decay on the production site then disposed of adopting conventional solutions.	Surface disposal facility (Very-low-level waste disposal facility in north-eastern France (Aube))	
Low level		Surface disposal facility (Low- and intermediate-level waste disposal facility in north-eastern France (Aube))[2]	Near-surface disposal facility[3] studied in accordance with Article 4 of the Planning Act of 28 June 2006 on the sustainable management of radioactive materials and waste.
Intermediate level			Deep disposal facility[4] studied in accordance with Article 3 of the Planning Act of 28 June 2006 on the sustainable management of radioactive materials and waste.
High level		Deep disposal facility[4] studied in accordance with Article 3 of the Planning Act of 28 June 2006 on the sustainable management of radioactive materials and waste.	

(1) The half-life of caesium-137, which is 30.07 years, marks the boundary between the notion of short-lived and long-lived. This figure is rounded up to the nearest whole number in the table for the sake of simplicity.
(2) The LILW disposal facility has taken over from the CSM disposal facility (Manche), which was closed in 1994.
(3) Near-surface means between the surface and a depth of 200 metres. A search is currently underway to find sites suitable for a new LLW-LL disposal facility.
(4) Deep disposal means at a depth of more than 200 metres. Andra is working on a repository project in the 250-square-kilometre transposition zone defined around the Meuse/Haute-Marne underground laboratory in 2005. The aim is to dispose of high-level and intermediate-level, long-lived waste in a single repository in a clay layer (Callovo-Oxfordian) 500 metres below the surface.

Notes:

- Tritiated waste cannot be accepted at surface disposal facilities without prior treatment and a period at a decay storage facility. The CEA conducted a study on the storage of this type of waste, in accordance with Article 9 of the Decree of 16 April 2008 [II]. The study was carried out as part of a project focusing on the storage of tritiated waste with no management solution, and the conclusions were handed in to the Minister of Ecology, Energy, Sustainable Development and Territorial Planning (MEEDDAT) at the end of 2008 (see Box 3.2 in Chapter 3);
- the processes used for disposing of sealed sources at existing or planned facilities were studied by Andra as part of the Radioactive Materials and Waste Management Plan, in accordance with Article 8 of the Decree of 16 April 2008 [II]. The report was handed in to the MEEDDAT at the end of 2008 (see Box 3.1 in Chapter 3).

Characteristics of the various waste categories

High-level waste (HLW)

Although this waste represents only a small volume, it accounts for most waste-related radioactivity. It is produced for the most part by the nuclear power industry. It consists of non-recyclable radioactive elements resulting from spent fuel or reprocessing as it is often known. This waste is mixed with a glass matrix then poured into stainless steel containers. Because of its high radioactivity, some of this waste gives off heat.

It contains fission products (e.g. caesium-134 and -137, strontium-90), activa-

[II] Decree 2008-357 of 16 April 2008 which implements Article L542-1-2 of the French Environmental Code and defines requirements relating to the Radioactive Materials and Waste Management Plan.

3 This means a facility designed to accommodate radioactive waste permanently.

tion products (e.g. cobalt-60, which decays in a few decades) and minor actinides, such as curium-244 and americium-241).

Intermediate-level, long-lived waste (ILW-LL)

Most of this waste is made up of the structures surrounding spent fuel, such as cladding hulls and end caps, or residue from nuclear facility operation (waste from effluent treatment, equipment, etc.). It is characterised by the significant presence of long-lived radionuclides (e.g. nickel-63).

Most of this HLW and ILW-LL is currently stored at spent fuel processing plants and at CEA research centres. Deep disposal studies are conducted within the framework of the Act of 28 June 2006. The activity level of HLW is in the region of several tens of billions of Becquerels (Bq) per gramme, while for ILW-LL, it is generally between a million and a billion Bq/g.

Low-level, long-lived waste (LLW-LL)

This consists mainly of two types of waste, called "radium-bearing" and "graphite" waste:

- radium-bearing waste contains naturally-occurring radionuclides, including a significant amount of radium and/or thorium. It comes from research activities and the chemical processing of ores. Other radium-bearing waste comes from the cleanup of legacy sites contaminated by radium, secured by Andra as part of the activities it performs in the general interest;
- graphite waste comes from the dismantling of the earliest nuclear power plants and a number of experimental reactors that have now been decommissioned.

This category also includes other types of waste such as lightning rods containing radium or americium, certain spent sealed sources and some old bitumen waste.

The important characteristic for this type of waste is the quantity of long-lived radionuclides it contains. Its activity level is generally between:

- a few tens of Bq and a few thousand Bq/g in the case of radium-bearing waste. The radionuclides are essentially long-lived alpha-emitters;
- ten thousand and a hundred thousand Bq/g in the case of graphite waste[4]. The radionuclides are essentially long-lived beta-gamma emitters.

Low- and intermediate-level, short-lived waste (LILW-SL)

This mainly concerns waste related to maintenance work (clothes, tools, filters, etc.) and the operation of nuclear facilities (liquid effluent treatment or gasous effluent filtering). It can also come from cleanup and dismantling operations on these facilities.

Since 1992, it has been disposed of at the CSFMA low- and intermediate-level waste disposal facility (Aube). The facility took over from the CSM disposal facility (Manche), which closed down in 1994.

This long-term management solution has existed since 1969, when France stopped dumping low-level waste at sea (see Appendix 5).

Low- and intermediate-level, short-lived waste contains short-lived radionuclides with a maximum half-life of 31 years (e.g. cobalt-60, caesium-137). The presence of long-lived radionuclides in this waste is strictly limited by disposal facility acceptance specifications.

The activity level of this waste is generally in the range of a few hundred to one million Bq/g.

LILW-SL containing significant quantities of tritium calls for a specific man-

4 The activity level of some graphite waste exceeds a hundred thousand Bq/g. There is only a small quantity of this type of waste, however, and the activity level in question includes all the radionuclides found in the waste and not just the long-lived ones.

agement solution. Although tritium is a short-lived radioelement, it is hard to confine. Once it has been placed in the disposal facility, it can easily migrate to the environment where it may leave detectable traces. Most of this waste results from activities related to the nuclear deterrent. In accordance with Article 9 of the Decree of 16 April 2008 [II], the CEA has studied solutions for storing this waste to reduce its radioactivity before placing it in a surface or near-surface disposal facility. This study was part of the project focusing on the storage of tritiated waste with no management solution, referred to in Section 1.4.6. After the storage period, this waste will be sent to the VLLW or LILW-SL disposal facility, depending on its activity level and residual gas release rate.

Very-low-level waste (VLLW)

VLLW lies somewhere between conventional waste (article L 541 of the Environmental Code) and low-level waste (LILW-SL or LLW-LL). This is because France, unlike other countries, has no preset clearance limits for waste that is or is likely to be very slightly radioactive (see Subchapter 1.1).

It mostly comes from the dismantling of nuclear facilities or from conventional industries that use naturally-occurring radioactive materials. This category generally concerns inert waste, such as concrete, rubble and earth.

Since 2003, this waste has been disposed of at the VLLW surface disposal facility (CSTFA, Aube).

VLLW production will increase considerably as large-scale dismantling begins on the nuclear power plants currently in operation.

The activity level of this type of waste is generally below 100 Bq/g. Graduated acceptability limits can be defined for the disposal of certain radionuclides.

It must be remembered that in the past, large volumes of long-lived waste, residues left over from uranium ore processing, known as tailings, were produced. These have a similar activity level to VLLW. Tailings are accounted for in the Geographical Inventory of the National Inventory and disposed of in specific facilities on or near the former mining sites. They are not handled by the VLLW disposal facility. Note that the radiological activity level of some of these tailings makes them more like LLW-SL.

More broadly, the MIMAUSA inventory, which can be consulted (in French) on the MEEDDAT website (www.ecologie.gouv.fr/etat-radiologique-des-sites.html), provides the most exhaustive inventory possible of uranium ore exploration, extraction and processing activities in metropolitan France.

A report on the long-term health and environmental impact of the disposal sites for these mine tailings was prepared by AREVA in accordance with Article 10 of the Decree of 16 April 2008 [II] and submitted to the Ministry of Ecology, Energy, Sustainable Development and Territorial Planning.

[II] Decree 2008-357 of 16 April 2008 which implements Article L542-1-2 of the French Environmental Code and defining requirements relating to the Radioactive Materials and Waste Management Plan.

sources
of radioactive waste

1.3

The many uses of the properties of radioactivity have led to the production of radioactive waste since the beginning of the 20th century. Most of the waste comes from nuclear power plants, spent fuel processing plants and other civil and military nuclear facilities that have developed over the past decades. Research laboratories and nuclear medicine departments also contribute to the production of radioactive waste, albeit to a lesser degree, as do certain other industries using radioactive materials.

The National Inventory describes the sources of radioactive waste, divided into twelve activity sectors, as a result of which radioactive waste is produced, held or managed.

These twelve activity sectors are listed in Table 1.2 below. Chapter 4 gives a more detailed description of the facilities concerned.

The twelve activity sectors are also matched against five major economic sectors. This simplifies the various statements included in Chapter 3 of the National Inventory.

The two approaches, the first based on the activity sector producing the waste, the other by economic sector, are complementary, even if some categories may concern more than one economic sector (see Table 1.3).

For instance, in the past the Marcoule facility processed fuel for military, civil and experimental use: thus three economic sectors are involved in the corresponding activity ("front end of the fuel cycle").

Similarly, the facilities in the storage and disposal facilities sector (activity sector 12), handle waste from many different sources, so it concerns all five economic sectors (see Table 1.3).

Lastly, Chapter 3 also includes a distribution of waste by holder.

Table 1.2: Radioactive waste producers or holders twelve activity sectors

1	FRONT END OF THE FUEL CYCLE
2	NUCLEAR POWER PLANTS
3	BACK END OF THE FUEL CYCLE
4	WASTE TREATMENT OR MAINTENANCE CENTRES
5	CEA CIVIL R&D CENTRES
6	RESEARCH CENTRES EXCLUDING THE CEA: physics, chemistry, biomedical research
7	MEDICAL ACTIVITIES: diagnostics, therapeutics, analyses
8	MISCELLANEOUS INDUSTRIAL ACTIVITIES: manufacture of sources, monitoring, special objects
9	NON-NUCLEAR INDUSTRIES USING NATURALLY-OCCURRING RADIOACTIVE MATERIAL
10	RESEARCH, PRODUCTION OR EXPERIMENTATION CENTRES WORKING FOR THE NUCLEAR DETERRENT
11	DEFENCE, DGA, SSA, ARMY/AIR FORCE/NAVY, GENDARMERIE FACILITIES
12	STORAGE AND DISPOSAL FACILITIES

Category 12 is not really a "waste-producing activity". It covers sites (Andra and "legacy" repositories) where waste from all sources is stored or disposed of. Even if the operation of some of the facilities concerned may produce radioactive waste, they are mentioned in this report basically because they constitute holding areas.

Table 1.3: Activity sectors and economic sectors that produce radioactive waste

	Activity sectors	Economic sectors
1	FRONT END OF THE FUEL CYCLE	• Nuclear power industry • Defence (marginal)
2	NUCLEAR POWER PLANTS	• Nuclear power industry
3	BACK END OF THE FUEL CYCLE	• Nuclear power industry • Research (marginal) • Defence (research)
4	WASTE TREATMENT OR MAINTENANCE CENTRES	• Nuclear power industry • Defence (research)
5	CEA CIVIL R&D CENTRES	• Research • Medical
6	RESEARCH CENTRES EXCLUDING THE CEA: physics, chemistry, biomedical research	• Research • Medical
7	MEDICAL ACTIVITIES: diagnostics, therapeutics, analyses	• Medical
8	MISCELLANEOUS INDUSTRIAL ACTIVITIES: manufacture of sources, monitoring, special objects	• Industry apart from nuclear power
9	NON-NUCLEAR INDUSTRIES USING NATURALLY-OCCURRING RADIOACTIVE MATERIAL	• Industry apart from nuclear power
10	RESEARCH, PRODUCTION OR EXPERIMENTATION CENTRES WORKING FOR THE NUCLEAR DETERRENT	• Defence
11	DEFENCE, DGA, SSA, ARMY/AIR FORCE/NAVY, GENDARMERIE FACILITIES	• Defence
12	STORAGE AND DISPOSAL FACILITIES	• Nuclear power industry • Research • Medical • Defence • Industry apart from nuclear power

radioactive
waste management

1.4

1.4.1 Those responsible for radioactive waste management in 2008

Radioactive waste management is strictly regulated at both national and international levels. In particular, France has signed the **Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management,** drafted under the aegis of the United Nations [III], which defines management principles.

The French Government has defined and implemented a rigorous public policy on radioactive waste. This was defined in a legislative framework in 1991 (in the Act of 30 December 1991) [IV]) then consolidated in 2006 (with the Act of 28 June 2006 [I]).

Led by the **General Directorate for Energy and Climate (DGEC)** at the Ministry of Ecology, Energy, Sustainable Development and Territorial Planning, the policy is built around three pillars:

- a National Radioactive Materials and Waste Management Plan [V].The plan is updated by the Government every three years and defines a scheduled programme of research and other activities;
- provisions for independent assessment of research work, public information and dialogue with all stakeholders;
- guaranteed funding: in accordance with Article L. 110-1 of the French Environmental Code, which stipulates that "the costs arising from measures to prevent, reduce or combat pollution must be borne by the polluter"; it is for the producer of the waste to finance its long-term management.

The National Radioactive Materials and Waste Management Plan draws on data from the National Inventory to identify cases where there is no long-term waste management solution, then defines actions and deadlines to remedy the situation.

The General Directorate for Risk Prevention (DGPR) at the Ministry of Ecology, Energy, Sustainable Development and Territorial Planning, deals with matters relating to sites contaminated by radioactivity (see Chapter 5) and defines regulations applicable to facilities classified for environmental protection, including conventional waste disposal facilities.

On matters of general scientific interest, particularly those relating to nuclear and space programmes, the French parliament has set up an assessment board of its own, called the **Parliamentary Office for the Evaluation of Scientific and Technology Choices (OPECST).** It organises hearings of parties concerned with radioactive waste management and publishes evaluation reports and recommendations that can be consulted on www.senat.fr/

[I] Planning Act 2006-739 of 28 June 2006 on the sustainable management of radioactive material and waste.

[III] Joint convention on the safety of spent fuel management and the safety of radioactive waste management, available on:
www-ns.iaea.org/conventions/waste-jointconvention.htm

[IV] Act 91-1381 of 30 December 1991 on radioactive waste management research.

[V] PNGMDR (French National Radioactive Materials and Waste Management Plan), available on www.industrie.gouv.fr/energie/nucleair/pngmdr.htm opecst.

The French High Committee for Transparency and Information on Nuclear Safety (HCTISN) is a body set up for information, consulting and debate concerning risks relating to nuclear activities and their impact on human health, the environment and nuclear safety. It was created by the Act of 13 June 2006 on transparency and nuclear safety [VI]. The Committee's reports and recommendations can be consulted on www.hctisn.fr.

Andra, the French National Radioactive Waste Management Agency is a public commercial and industrial organisation set up by the Act of 30 December 1991. It was assigned further responsibilities by the Act of 28 June 2006. Andra is independent of radioactive waste producers and supervised by the Ministries for Energy, the Environment and Research. It provides special support for the French Government by implementing its radioactive waste management policy. The Government sets out Andra's objectives in a four-yearly contract. The latest contract covers the period from 2009 to 2012. It can be consulted on Andra's website on www.andra.fr [VII]. Andra is responsible for the **sustainable management of radioactive waste in France.** French policy favours the disposal solution. Disposal takes place after treatment and, if necessary, a period of storage. Andra provides the Government with expertise and know-how for the design, operation and monitoring of radioactive waste disposal facilities, **affording long-term protection for human health and the environment against the impact of this waste.**

Andra provides the Government with expertise and know-how for the design, operation and monitoring of radioactive waste disposal facilities, affording long-term protection for human health and the environment against the impact of this waste.

The Agency carries out various activities:

1/ **operating two existing facilities** in the north-east of France (Aube), designed for the disposal of low- and intermediate-level, short-lived waste (LILW-SL) and very-low-level waste (VLLW); **monitoring** the CSM disposal facility, France's first surface disposal facility for low- and intermediate-level waste located in the Manche in north-western France, now in the post-closure phase;

2/ **studying and designing sustainable management solutions** for waste for which no dedicated facilities currently exist:

- **near-surface disposal facility for low-level, long-lived waste,** such as radium-bearing and graphite waste (LLW-LL project);
- **reversible deep disposal facility for high-level and intermediate-level, long-lived waste** (HLW and ILW-LL project);

3/ **handling radioactive waste that does not come from the nuclear power sector** (but from hospitals, research laboratories, universities, etc.) and radioactive objects in the possession of individuals (old luminescent time pieces, radium-bearing items for medical use, natural salts used in laboratories, some minerals, etc.). At the request of the owner or the public authorities, Andra oversees the rehabilitation of old sites contaminated by radioactivity, such as the laboratories built for Marie Curie for example. It does this with the help of the French **National Commission for Radioactivity Assistance (the CNAR),** which gives an opinion on the use of the Government subsidy set aside for Andra's activities carried out in the general interest: cleaning up contaminated sites or handling waste (see Chapter V);

4/ **providing specialist and non-specialist information**, in particular, through the three-yearly publication of the **National Inventory of Radioactive Materials and Waste,** helping to spread scientific and technical culture by publishing documents, organising exhibitions and visits to its facilities, as well as disseminating its expertise in France and abroad.

The National Review Board (CNE), was created by the Act of December 1991 to report on the progress and quality of research into high-level and long-lived radioactive waste management. The Board, which was confirmed in its

[VI] Act 2006-686 of 13 June 2006 on transparency and nuclear safety.

[VII] Four-yearly contract between Andra and the French Government for the period 2009-2012, available on www.andra.fr role by the Act of 28 June 2006, publishes an annual report which is submitted for consideration by Parliament [VIII]. The report is published.

The French Nuclear Safety Authority (ASN) supervises waste producers and Andra in their nuclear activities and those requiring radiation protection measures. It also examines licensing procedures for basic nuclear installations, including radioactive waste treatment, conditioning and disposal facilities. It grants individual licences for the possession of certain radioactive sources or equipment using ionising radiation.

Radioactive waste producers are industrial companies that generate radioactive waste as a result of the services they provide or their production activities (nuclear power generation, research, national defence, hospitals, chemicals, etc.). They are responsible for managing this waste effectively before it is passed on to Andra. More especially, they must define waste treatment and conditioning processes (see Section 1.4.3), using the range of technology available. They carry out waste conditioning in accordance with the strict quality assurance procedures required by regulations [IX]. They must also store waste for which no management solution is currently available. In addition, they are responsible for transporting other conditioned waste to Andra's centres. "Small-scale nuclear activities" waste producers, such as non-CEA research laboratories or hospitals, are the only exception to this rule. In this case, Andra assumes responsibility for collecting, treating and conditioning the waste.

1.4.2 General principles of radioactive waste management

Article L 541-1 of the Environmental Code lays down the following principles: prevention or reduction of waste production, producers' responsibility until the waste is eliminated, traceability and the need to inform the public. Moreover, a permanent solution may only be found for ultimate waste, i.e. waste which is not likely to be treated under the technical and economic conditions of the moment.

Regarding radioactive waste, the Environmental Code, as amended by the Act of 28 June 2006, stipulates that the sustainable management of radioactive material and waste of all kinds resulting, in particular, from the operation and dismantling of facilities using radioactive sources or materials, is guaranteed for the protection of human health and the environment and for safety purposes.

Many provisions have been made to ensure that this statutory framework is upheld:

- provisions relating to treatment/conditioning, transport and facilities: these are defined by the authorities responsible, which then check that they are applied;
- provisions to reduce the volume and toxicity of the waste from the outset and provisions for the sorting, treatment and conditioning of the waste produced and for identifying its radiological content: these are defined and implemented by the waste producers. The research and development work that is often required is carried out by various CEA organisations;
- the design and construction of waste facilities with the required safety level. These may be storage facilities (temporary solution), which are generally the responsibility of operators or waste producers, or dispos-

The Environmental Code lays down the following principles: prevention or reduction of waste production, producers' responsibility until the waste is eliminated, traceability and the need to inform the public.

[VIII] National Review Board reports available, for instance, on www.ladocumentationfrancaise.fr/rapports/index.html

[IX] Order of 10 August 1984 on the quality of design, construction and operation of basic nuclear installations.

al facilities[5] (permanent solution) for which Andra is responsible (see Section 1.4.1);
- transport, storage and disposal operations, along with traceability and monitoring, including over the long term in the case of disposal facilities;
- provisions relating to public information.

1.4.3 Radioactive waste treatment and conditioning

The waste must present characteristics compatible with its accommodation in a storage or disposal facility. These characteristics are defined by the waste facility operator in compliance with the rules set out by the Nuclear Safety Authority (ASN). Some of them cover the type of waste or its radioactive characteristics: for example, the disposal of liquids, fermentable waste or inflammable material is prohibited.
Other characteristics concern the object to be accommodated in its final form, i.e. after treatment and conditioning of the initial waste: for example, dimensions, falling weight impact strength, permeability, etc.

Treatment of radioactive waste consists in transforming the waste from its initial form to a form displaying characteristics that are better suited to long-term management, and in reducing its volume as much as possible. Examples are: liquid treatment, incineration, detritiation, immobilisation, compaction, vitrification and melting[6]
Furthermore, steps must be taken to avoid any risk of human irradiation or contamination and any attack on the integrity of the waste during transport or handling. The producer, the repository operator and the public at large are all concerned. Depending on the planned disposal solution, the waste must generally be conditioned to guarantee the confinement of its radioactivity.
Conditioning consists in incorporating the waste in a material, referred to as the "matrix", which protects the waste or confines its radioactivity more effectively. The "matrix + waste" combination is placed in a suitable container which may also help to confine the radioelements present.
The use of **a matrix** is generally required, but there are exceptions to this rule. Nowadays glass matrices are used for conditioning the most highly radioactive waste, which comes from spent fuel fission products and minor actinide solutions. Cement-, polymer-, or bitumen-based materials are used for conditioning intermediate- or low-level waste.
Containers are made of concrete, non-alloy steel (ordinary steel) or alloy steel (stainless). In some cases, the waste is not containerised prior to disposal, especially if it is very-low-level waste or if it is in a form that makes it safe for direct disposal, such as steel ingots.
Conditioned waste is generally referred to as waste packages**.**
Nowadays, the waste producers are responsible for defining and implementing the conditioning modes for most of the waste they produce, subject to agree-

5 Some former disposal facilities - or "legacy" repositories - are special cases. They are addressed in Chapters 3 and 4.

6 Liquid treatments are aimed at concentrating the radioactivity in a smaller volume (concentration by evaporation) or trapping the bulk of radionuclides using chemical reagents. Some waste is incinerated if the technical conditions relating to its type and activity level are met. Scrap iron of moderate dimensions or waste such as rags or plastic is often compacted prior to conditioning.

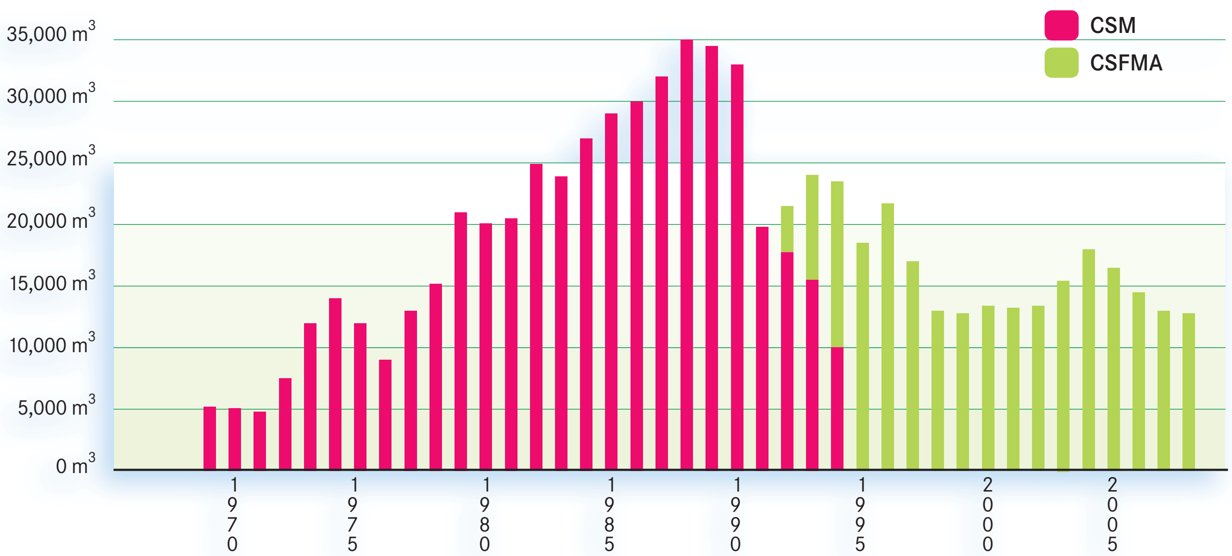
ment by Andra and under ASN control. Unconditioned stocks are made up of "buffer items" awaiting conditioning.

In some cases, however, described in Chapter 4, legacy waste, which was either treated in line with the current standards of the time, or stored in bulk at storage facilities, must be recovered for conditioning, reconditioning, or storage under improved conditions, depending on the case. This is referred to as waste recovery and conditioning. It is done by AREVA at the La Hague site and by the CEA at some of its sites, such as Marcoule and Cadarache in particular. The Act of 28 June 2006 stipulates that intermediate-level, long-lived waste produced before 2015 must be conditioned by its owners by 2030.

1.4.4 Reducing waste volumes to make the best use of precious disposal capacity

One of the purposes of treatment and conditioning is to reduce volumes, which, in the case of LILW-SL, is reflected in the significant drop in the

Figure 1.1: Waste package deliveries to the CSM disposal facility (Manche) then to the CFSMA disposal facility (Aube)



The figure shows a period of growth in waste production, related to the increase in capacity in the nuclear power industry, followed by a period of volume reduction. The quantity of LILW-SL produced by nuclear power plants, expressed according to electrical power capacity, has fallen considerably in recent years, with the volume of waste packages concerned dropping from about 80 m^3/TWh of electricity production in 1985 to around 11 m^3/TWh today.

This figure represents an average production of 75 m^3 of waste packages for surface disposal per reactor unit. This reduction in solid waste has not led to any increase in liquid releases. Over the same period, the mean activity (excluding tritium) of liquid effluents released to the environment by nuclear power plants has been halved.

quantity of waste delivered to Andra's LILW disposal facility during the 1990s (Figure 1.1).

The process of supercompacting ILW-LL, carried out by AREVA at its La Hague plant, has reduced waste from spent fuel structures by a factor of 4 (see illustration). This type of waste used to be cemented.

Recycling effluent from the La Hague plant and vitrification of the remaining waste have drastically reduced the quantities of bituminous waste produced (see illustration).

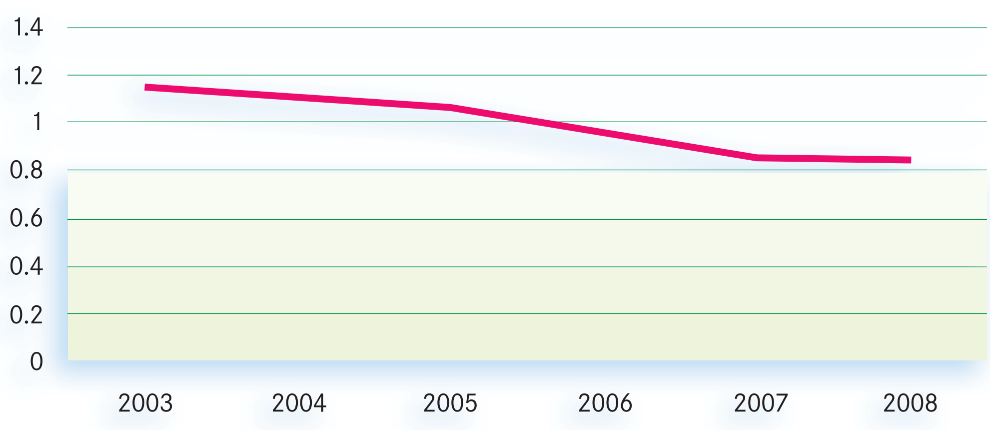
Bearing in mind processing plant design parameters, the annual volume of HLW and ILW-LL taken together has been reduced more than six-fold. It has dropped from a volume of around 3 m^3 per tonne of processed fuel, the volume expected by AREVA when the plants were designed, to less than 0.5 m^3 today.

This reduction in volume has been achieved through the research carried out in the nuclear power field. It has resulted in the following concrete actions, most of which were set up between 1985 and 2002:

- reduction of potential waste at source, sharing operating feedback and "good practices";
- modifications made to liquid effluent treatment, densification of conditioning for certain types of waste by grouping and/or precompacting. These improvements have been effective for waste coming directly from both reactor operation and servicing;
- commissioning of the melting and incineration units at the CENTRACO facility in Marcoule;
- decommissioning of the oldest facilities.

The volumes of very-low-level waste must still be reduced. Contrary to producers' forecasts, the density of waste delivered to the VLLW facility (CSTFA) for disposal has actually been reduced. Figure 2.2 illustrates the trend in densities delivered since the facility opened in 2003.

Figure 2.2: Density of deliveries to the CSTFA



Examples of management solutions

Vitrified waste

In the processing plants, the spent fuel is dissolved, the recoverable material is separated out and the residue is stored in tanks.

The stored solutions are then calcined and incorporated into a molten glass paste. The resulting product is then poured into a container, known as the CSD-V.

The glass matrices are stored under very strict safety conditions in ventilated shafts designed to allow heat removal.

The study of a deep disposal solution for this waste is required by the Act of 28 June 2006.

Spent fuel structural elements

The first step in spent fuel processing consists in shearing and dissolving the material contained in the structural elements. Once emptied, these elements are still radioactive and are considered as waste. They are sometimes called "hulls and end caps".

This type of waste was cemented in the past but is now compacted at AREVA's La Hague hull compacting facility.

They are then placed in stainless steel containers (called "CSD-Cs") and stored at the La Hague site.

The study of a deep disposal solution for this waste is required by the Act of 28 June 2006.

Examples of management solutions

Bituminised waste

The effluents generated by treatment facility processes are contaminated by radioactivity and must be treated. The method adopted at La Hague involves precipitating most of the radioactivity by adding chemical reagents, leaving "sludge".

The sludge is then mixed with bitumen (here the STE3 facility at La Hague).

The drums of bituminised waste are stored at La Hague.

As required by the Act of 28 June 2006, research is underway to find a disposal solution for the bituminised waste from La Hague.

LILW-SL: examples of EDF filters

The filters installed on the reactor coolant system of EDF power plants may be contaminated. They are regularly changed and treated as LILW-SL.

Conditioning involves placing them in a concrete container that is injected with mortar to immobilise the filter inside.
The mortar and container ensure that the radioelements are confined. The packages (mortar + container) are then delivered to the CSFMA disposal facility (Aube), where they are placed in the engineered repository structures.

1.4.5 Existing solutions for the long-term management of radioactive waste

- Surface disposal of **low- and intermediate-level, short-lived waste**

The purpose of surface disposal of this category of waste is to isolate the radioactive products from the environment for as long as it takes for the radioactivity to decay to a negligible level. There are two sites in this category in France: the CSM disposal facility (Manche) and the CSFMA disposal facility (Aube). The CSM disposal facility no longer receives waste and is in its monitoring phase. The CSFMA disposal facility has been in operation since 1992.

A detailed description of this existing management solution is given in Appendix 3.

- Surface disposal of **very-low-level waste**

Andra has developed a specific solution for very-low-level waste at the request of the authorities. Its basic design is inspired by that of the hazardous waste landfill sites used in the chemical industry. The facility was commissioned in August 2003.

A detailed description of this existing management solution is given in Appendix 3.

The following table gives a summary of existing solutions.

Table 1.4

Disposal facilities	Capacity of facility	Quantities disposed of	Examples of waste	Remarks
CSM waste disposal facility (Manche)	–	527,225 m^3	**LILW-SL:** • Solid maintenance operation waste • Cemented sludge • Resins	• Closed in June 1994 • The post-closure monitoring phase began in January 2003
CSFMA disposal facility (Aube)	1,000,000 m^3	208,053 m^3 as at 31 December 2007	**LILW-SL:** • Solid maintenance operation waste • Cemented sludge • Resins	Commissioned in January 1992
CSTFA disposal facility (Aube)	650,000 m^3	89,331 m^3 as at 31 December 2007	**VLLW:** • Rubble and scrap iron from dismantling operations • Special industrial waste	Commissioned in August 2003

Waste stored on site for radioactive decay

Hospital waste contains very-short-lived radionuclides used for diagnostic or therapeutical purposes. It is managed on site. The waste is stored until its radioactivity decays, which takes from a few days to a few months. After this, it is no longer considered as radioactive waste and is disposed of by conventional methods.

1.4.6 Solutions being considered for the long-term management of radioactive waste

Storage solutions for tritiated waste (LILW and VLLW)

Most tritiated waste is either too highly active or gives off too much gas for it to be handled by the disposal facility in the disposal facility in north-eastern France. Tritium is a very mobile element and could leave detectable traces in the environment. Given the current lack of solutions, the Act of 28 June 2006 has entrusted the CEA with the task of developing storage solutions for tritiated waste by 31 December 2008. The solution proposed should reduce the activity level of this waste with a view to disposal at a surface or near-surface repository.

The CEA, with the help of Andra and the ITER France Agency, has prepared a report that proposes storage solutions for all tritiated waste, for which no current or planned solution exists, to allow time for radioactive decay prior to disposal. The report was submitted to the Ministry of Ecology, Energy, Sustainable Development and Territorial Planning on 23 December 2008. It will be published as part of the National Radioactive Materials and Waste Management Plan. The French Nuclear Safety Authority should give its opinion on the report in the summer 2009, at the Ministry's request.

This possible management solution, and the conclusions of the report are also described in Chapter 3.

Project for a near-surface repository for low-level, long-lived waste (LLW-LL)

The Planning Act of 28 June 2006 tasked Andra with developing near-surface disposal solutions for graphite waste (from dismantling operations on first-generation, gas-cooled, nuclear power reactors) and radium-bearing waste. Andra has also been asked to consider whether these solutions would be compatible with the handling of other types of low-level, long-lived waste, in particular spent sealed sources and low-level radioactive objects containing radium, thorium and uranium.

Disposal is being studied in a clay layer. The near-surface disposal facility could be commissioned by 2019.

A detailed description of this possible management solution is given in Appendix 3.

Project for a deep repository for high-level and intermediate-level, long-lived waste (HLW and ILW-LL)

The Planning Act of 28 June 2006 also tasked Andra with conducting studies and research activities to site and design a deep repository for the disposal of high-level and intermediate-level, long-lived waste. The Act stipulates that the repository should be consistent with the principle of reversible disposal for at least 100 years. Subject to licensing requirements, the facility should be commissioned in 2025.

The underground disposal installations will be located within a 250 km^2 area known as the "transposition zone", located in the Callovo-Oxfordian argillite formation, currently being explored from the Meuse/Haute-Marne underground laboratory.

A detailed description of this possible management solution is

given in Appendix 3.

Table 1.5 below summarises the possible management solutions described in the above section.

Table 1.5

<table>
<tr><th colspan="2"></th><th>Examples of waste</th><th>Remarks</th><th>Future milestones</th></tr>
<tr><td colspan="2">Tritiated LILW-SL</td><td>• Solid maintenance operation waste produced by weapons manufacture for the nuclear deterrent</td><td>• Act of 28 June 2006
• Study of decay storage facilities</td><td>ASN opinion on project documentation in 2009</td></tr>
<tr><td rowspan="2">LLW-LL</td><td>Radium-bearing waste</td><td>• "Technically enhanced" radioactive waste from non-nuclear industries
• Contaminated site cleanup products
• Miscellaneous objects</td><td rowspan="2">• Act of 28 June 2006
• Study of near-surface disposal</td><td rowspan="2">Industrial commissioning of the facility in 2019</td></tr>
<tr><td>Graphite waste</td><td>Sleeves and stacks</td></tr>
<tr><td colspan="2">Sources</td><td>Spent sealed sources used in industry, research or medical applications, smoke detectors, lightning rods, etc.</td><td>• Act of 28 June 2006
• Study to determine to what extent they are taken into account in existing or planned disposal solutions</td><td>ASN opinion on project documentation in 2009</td></tr>
<tr><td colspan="2">ILW-LL</td><td>• Fuel rod cladding
• Sludge from bituminised effluent treatment
• Cemented maintenance operation waste</td><td rowspan="2">• Act of 28 June 2006
• Study of deep disposal</td><td rowspan="2">Industrial commissioning of the facility in 2025</td></tr>
<tr><td colspan="2">HLW</td><td>Vitrified fission products and minor actinides</td></tr>
</table>

1.4.7 Special cases

Some waste calls for specific management modes:

- Waste with technically enhanced radioactivity. This type of waste is not the result of nuclear activities as the materials making it up were not used for their radioactive properties. It chiefly concerns waste from the chemical or metallurgical industries (phosphate fertilisers, rare earths, zircon sand, etc.). The Circular of 25 July 2006 [X] issued by the Ministry of Ecology, Energy, Sustainable Development and Territorial Planning (MEEDDAT) provides for specific management of this category of waste in a conventional waste disposal facility. Examples of this might be the disposal of waste from the demolition of old factories, equipment or process residues. The circular lays down strict conditions for the disposal of such waste at conventional facilities. Operators must ensure that a specific impact study is conducted for each application to a disposal facility in order to assess the radiological risk. This type of study is codified. It must be conducted in accordance with the technical guide published by the MEEDDAT and the IRSN in 2006. It must demonstrate that the disposal of this type of waste requires consideration to be given to radiation protection measures, both for the operating personnel and the surrounding population, including over the long term. The circular also stipulates that this management mode is intended only for limited, clearly identified and characterised batches of waste. Periodic statements, including those concerning any waste with technically enhanced levels of radioactivity, must be submitted to the local information committees of the disposal facilities to keep the surrounding population properly informed. The MEEDDAT monitors management reports for this waste at the national level.
- Some objects are not directly concerned by one of the existing management solutions (see Section 1.4.5) or those being considered (see Section 1.4.6). These include a small amount of specific waste, referred to as mixed, because it displays high chemical toxicity or may be infectious in addition to being radioactive (e.g. waste containing mercury). A solution needs to be found here. These objects also include waste which, depending on the outcome of future technical and economic studies, may either by managed through one of the solutions defined earlier or require specific management: examples are highly radioactive oils, solvents, sludge and distillates.

[X] Circular of 25 July 2006 BPSPR/2006-217/HA

drawing up the National Inventory: methodology

2.1 procedures adopted for surveying radioactive materials and waste

2.1.1 The new legal framework

Article L542-12 of the French Environmental Code, amended by the Act of 28 June 2006, states that Andra should establish, update every three years and publish the Inventory of Radioactive Materials and Waste existing in France, as well as its location on the national territory, listing the waste defined under Article L542-2-1 by country of origin[1]. This extends the Agency's responsibility for informing the public of the nature and location of radioactive waste, already defined in the Act of 30 December 1991.
The Council of State Decree of 29 August 2008, [I] which implements Article 22 of the Act of 28 June 2006, and a Ministerial Order of 9 October 2008 [II] define the obligations of the producers and holders of radioactive material and waste regarding declarations.
The 2009 edition of the National Inventory is broader in scope than its predecessors. In addition to the information on radioactive materials and waste given in the 2004 and 2006 editions, the new edition includes information on storage facilities for waste awaiting a definitive management solution (see Chapter 3 and Appendix IV), in accordance with the Decree of 16 April 2008, which lays down requirements relating to the National Radioactive Materials and Waste Management Plan (PNGMDR) [III].

2.1.2 Principles on which the National Inventory is based

The compilation of the National Inventory of Radioactive Materials and Waste is underpinned by strict methodology and meticulous data verification procedures.

It has two aims:
- to list all the waste and materials[2] of each producer or holder in France. Andra has performed this survey since 1992. Originally based on voluntary declarations by the waste producers and holders, this activity now falls within the recent regulatory framework described in the above section;
- to provide an overview of present and future waste volumes, based on projected scenarios with snapshots of material and waste stocks on key dates. These dates were defined in a ministerial order in 2008.

The figures for existing waste stocks given in the 2009 edition of the National Inventory are for the end of 2007, while forecasts are made for 2020 and 2030 on the dates defined in the Ministerial Order of 9 October 2008 [IV].

[I] Decree 2008-875 of 29 August 2008 which implements Article 22 of the Planning Act of 28 June 2006 on the sustainable management of radioactive materials and waste.

[II] Order of 9 October 2008 on the type of information that responsible entities in charge of nuclear activities and the companies identified under Article L.1333-10 of the French Public Health Code are obliged to collate, update and periodically send to the National Radioactive Waste Management Agency.

[II] Decree 2008-357 of 16 April 2008 which implements Article L542-1-2 of the French Environmental Code and defines requirements relating to the Radioactive Materials and Waste Management Plan.

[IV] Order of 9 October 2008 on the information to be passed on to the National Radioactive Waste Management Agency to prepare the 2009 edition of the National Inventory of Radioactive Materials and Waste.

1 Radioactive waste originating from spent fuel processing.

2 Mandatory declarations relating to materials only concern the operators of basic nuclear installations and certain facilities classified for environmental protection. They are defined in the Decree of 29 August 2008.[I].

The National Inventory is governed by five guiding principles which also ensure that it is reliable, of the highest quality and fit for use as a reference

Availability of information

The duty to inform citizens is fulfilled by providing data that can be understood by a broad readership and avoiding excessive use of technical vocabulary. At the same time, the aim is to help the authorities prepare the National Radioactive Materials and Waste Management Plan, by providing them with a realistic inventory that reflects the waste producers' position at the time of their declarations.

Comprehensiveness

The National Inventory provides a survey not only of existing waste resulting from recent and current activities, but also of that produced in the past, since the earliest uses of the properties of radioactivity for industrial, military and medical purposes. The aim is to present a "snapshot" of all the waste located in France at a given time (excluding releases, see Chapter 1, Subchapter 1.1), regardless of its physical or chemical state, conditioning status, form - liquid or solid, and activity level - high or low. The scope of the survey is not restricted to waste disposal or storage facilities. It also covers all installations that contain waste - even temporarily - awaiting collection by Andra, for example medical research or university laboratories. It also includes radioactive materials.

Neutrality

The National Inventory provides a transcript of the collected data in a factual way, without pronouncing judgment on the potentially hazardous nature of the products described.

Transparency

The National Inventory provides an overview of radioactive materials and waste, regardless of their origin. This approach is meant to complement the efforts made to work transparently, something to which the public authorities, waste producers and the Nuclear Safety Authority (ASN) have been committed for several years.

Responsibility of parties for their declarations and validation of management solutions by Andra

The National Inventory reproduces the data given in the declarations submitted by waste producers. Each producer is therefore responsible for the declaration it submits. Although Andra has no policing powers, the regulatory provisions stemming from the Act of 28 June 2006, described in Section 2.1.1 entitle it, if necessary, to inform the appropriate authorities should a waste producer or holder fail to fulfil its obligations regarding declarations. Furthermore, under Article 2 of the Decree of 16 April 2008 relative to PNGMDR requirements [III], Andra checks whether the waste management solution proposed by the producer is suitable.

The National Inventory provides an overview of radioactive materials and waste, regardless of their origin.

2.1.3 The role of the steering committee in preparing the National Inventory

A steering committee, chaired by Andra's Chief Executive Officer and made up of members from outside the Agency, oversees the preparation of the National Inventory. Membership of the steering committee is as follows:

- representatives of the government bodies concerned (General Directorate for Energy and Climate [DGEC] and General Directorate for Risk Prevention [DGPR] of the Ministry of Ecology, Energy, Sustainable Development and Territorial Planning [MEEDDAT]);
- a representative of the Nuclear Safety Authority (ASN);
- representatives of the main waste producers (both in and outside the nuclear power sector);
- a representative of the Parliamentary Office for the Evaluation of Scientific and Technology Choices (OPECST) in an observer capacity;
- a representative of the National Review Board (CNE, see Section 1.4.1), in an observer capacity.

The steering committee validates the overall consistency of the volumes of existing and future material and waste published in the National Inventory, as well as the assumptions made in the projected scenarios (the main difficulty here is to allow for possible changes in the strategy adopted by the various parties involved and to examine the related technical documentation). The committee also validates the data given in the National Inventory.

2.2 survey of existing radioactive waste

In view of its knowledge of waste, production sites and management solutions, Andra is ideally suited for the inventory and survey tasks entrusted to it by the French Environmental Code. The information it gathers is correlated with the various other sources to which it has access.

2.2.1 Waste storage or disposal sites

These sites are shown by administrative region in a separate volume (called the Geographical Inventory), which provides the relevant data for this Synthesis Report.

A series of record sheets presents the sites where radioactive waste is produced, treated, conditioned and stored and which are operated by major waste producers and holders.

Other sheets present:
- Andra's waste disposal sites (see Subchapter 4.12);
- sites that have been contaminated by radioactivity, cleaned up or in the process of being cleaned up, where waste is stored (see Chapter 5);
- former mining sites where tailings from uranium ore processing have been definitively disposed of (see Chapter 3 and Subchapter 4.1);
- legacy waste disposal sites (see Chapter 3 and Subchapter 4.12).

Tables list "diffuse" nuclear waste producers - also known as "small-scale nuclear activities" waste producers.

Waste storage or disposal sites already surveyed: data update

Data is updated by site operators according to the principles set out in Section 2.1.2.

It should be borne in mind that contaminated sites[3] are a case apart, as the party making the declaration is not always a clearly identified industrial firm. Declarations are often made by a natural person, or a local authority, or a liquidator if the site has been abandoned by the industrial firm previously occupying it. Contaminated sites where management is deficient are managed by Andra as part of its activities in the general interest. Thus the Agency makes the declaration where necessary.

3 Contaminated sites that have been recognised as such by the authorities.

Identifying new sites

The obligations of waste producers or holders regarding declarations, described in Section 2.1.1, do not, however, release the Agency from its duty to ensure that the survey is comprehensive, by cross-checking various sources of information. When the presence of radioactive waste has been proven on sites that are not yet listed, the sites in question are incorporated into the National Inventory at the next update.

Particular attention is required in three areas that do not concern institutional producers.

"Small-scale nuclear activities" waste producers in hospitals and universities

These are hard to identify because of their large number, scattered location and irregular production of radioactive waste. New holders may thus appear with each new inventory, while others may disappear. The 12 Regional Officers of the INSERM, the 19 Regional Offices of the CNRS, and the 22 regional research centres of the INRA were all contacted for the purposes of this National Inventory. A significant number of previously unlisted "small-scale nuclear activities" waste producers was identified thanks to this initiative.

Some former or forgotten industrial wasteland

Risk studies carried out on former industrial sites, historical surveys of certain industrial activities at various moments in the past, or quite simply chance, may reveal the presence of radionuclides. A few years ago, investigations into industries that used radium in the early twentieth century led to the discovery and inclusion of previously unknown, radium-contaminated sites.

Further to the Interministerial Circular of 17 November 2008 on Andra's activities in the general interest, and the management of certain types of radioactive waste and sites contaminated by radioactivity, the Regional Directorates for Industry, Research and the Environment (DRIRE) and the Nuclear Safety Authority (ASN) can also bring to Andra's attention information to complete or add detail to the survey of contaminated sites. After "confirmation", these sites are managed by Andra as part of its activities in the general interest. The sites are then listed in the National Inventory (see Chapter V). The Geographical Inventory includes record sheets listing sites where waste is stored.

Non-nuclear industries that generate radioactive waste

This category covers a wide variety of producers (in activity sectors related to chemicals, metallurgy or energy production). The waste they produce can sometimes exhibit low levels of radioactivity. Identification of this sector has seen an improvement in the past fifteen years and the survey gets better with each new edition of the National Inventory.

+ The obligations of waste producers regarding declarations do not release the Agency from its duty to ensure that the survey is comprehensive by cross-checking various sources of information.

2.2.2 Is the National Inventory really comprehensive?

Successive updates of surveys since 1993 have brought fuller and more detailed knowledge concerning the location of waste and some of its characteristics, as the producers themselves come to learn more about their waste products.
The issue of comprehensiveness is addressed at two levels: the location of sites where radioactive waste is present, and the quantities and category of the waste described at surveyed sites.
A producer may overlook some waste when making a declaration. As the major producers also declare their waste stocks to the Nuclear Safety Authority, there is little risk that anything will be omitted. The two declarations are generally compared by the producer or made jointly. In addition, the Nuclear Safety Authority carries out regular on-site checks on the declarations submitted.
AREVA is somewhat special in that waste stocks are also audited by a body authorised by its customers.
From one edition to the next, some facilities may no longer be included in the survey because they contain no more radioactive waste (e.g. dismantled and cleaned-up facilities). Conversely, new waste-producing facilities can appear. Over the past fifteen years, the National Inventory has made considerable headway in accounting for defence-related waste and in surveying fuel cycle and research facilities.
The fact that declarations have been governed by regulations since 2008 has led to the availability of an increased amount of data for this edition of the National Inventory[4]. Furthermore, in response to the incidents that occurred at the Tricastin site in the summer of 2008, the Ministry of Ecology, Energy, Sustainable Development and Territorial Planning asked the newly created High Committee for Transparency and Information on Nuclear Safety (HCTISN) (see Section 1.4.1) to make the necessary recommendations. As a result, more detailed information concerning a number of sites [5] has been provided in the National Inventory.
Notwithstanding the above, there are certainly some potential holders of radioactive waste that have never approached Andra[6], or radioactively contaminated sites still to be identified[7]. Andra, the IRSN and the public authorities have already conducted several campaigns to collect radioactive objects. Historical surveys are conducted to identify potentially contaminated sites that have been forgotten with the passing of time. Among the recommendations made by the High Committee for Transparency and Information on Nuclear Safety in answer to the Minister of State's request [V], recommendation 15 states that: "The High Committee recommends that the BASIAS site developed by the Ministry of Ecology in connection with former industrial or service activities should be extended to industrial sites liable to be affected by radioactive contamination." Implementation of this recommendation could well give rise to new historical surveys. Once "confirmed", some additional sites could be included in the National Inventory.
It remains very difficult, however, to guarantee the thoroughness of the survey for some activity sectors mentioned in Section 2.2.1 (hospitals, non-nuclear industries, etc.). This is true not only in terms of waste location but also as to whether waste is actually to be found on the listed sites.
As seen in Chapter 1, the very notion of "radioactive waste" is open to interpretation for certain types of waste displaying very low levels of radioactivity. Nonetheless, the National Inventory endeavours to be as exhaustive as possible.

The issue of comprehensiveness is thus addressed at two levels: the location of sites where radioactive waste is present and the quantities and category of the waste described at surveyed sites.

[V] "Opinion on radioecological monitoring of waters in the vicinity of nuclear facilities and on the management of former radioactive waste storage sites – 18 recommendations for improving information, transparency and consultation of stakeholders" which can be consulted online at www.developpement-durable.gouv.fr or www.hctisn.fr

4 This edition includes a more comprehensive survey of certain sites, as well as a survey for 11 new sites containing significant amounts of waste (the Geographical Inventory includes record sheets for these). Conversely, 7 sites no longer containing any waste at the end of 2007 have been removed from the Geographical Inventory.

5 These are the "legacy waste repository sites" described in Chapter 3 and Subchapter 4.12.

6 This category of waste holder should be limited by the regulatory provisions of 2008.

7 As mentioned earlier in this chapter, sites contaminated by radioactivity are incorporated in the National Inventory following "confirmation" by the authorities concerned.

accounting for and making projections on waste

2.3

2.3.1 The waste family principle

The survey conducted along the lines of the principles described earlier leads to a large quantity of waste being declared.
For the sake of simplicity and for forecasting purposes, the waste has been assigned to "families".
Each waste family is made up of waste that displays similar characteristics with respect to the criteria chosen for each group.
The 2009 edition of the National Inventory contains more than a hundred such families based on the following criteria:

- **the waste category within the radioactive waste classification by management solution,** from very-low-level to high-level waste (see Subchapter 1.2);
- **the industrial activity responsible for producing the waste package:** (see Subchapter 1.3);
- **the nature and physical and chemical characteristics of the raw waste prior to conditioning:** fission products and minor actinides, fuel assembly structures (cladding, end caps), water purification resins, sludge or concentrates, solid maintenance operation waste, etc. ;
- **the production status of the raw waste and package.** There are three possibilities for waste and waste packages:
  - waste production finished, waste production in progress, waste production not yet started;
  - package production finished, package production in progress, package production not yet started.
- **the actual or planned conditioning mode,** in particular, the material used to make the matrix and container (see Section 1.4.3);
- **conditioning status:**
  - Waste may come in three forms: unconditioned, pre-conditioned or conditioned;
  - pre-conditioned waste has undergone partial treatment or conditioning that will be part of the final waste package;
  - waste is said to be conditioned when it is part of a waste package (see Section 1.4.3).

The waste volumes given in the National Inventory are expressed in "m^3 conditioned equivalent", corresponding to:

- conditioning in a primary package (i.e. with no disposal package) for the following types of waste: HLW, ILW-LL and radium-bearing LLW-LL;
- conditioning in packages ready for disposal for the following types of waste: graphite LLW-LL, LILW-SL and VLLW.

Most countries have also adopted an inventory system based on a waste family principle. The degree of detail, however, varies from one country to another. The French National Inventory has sought the best compromise between the extremes. More families would no doubt have refined the description of radioactive waste but made it harder to read. Fewer families would have had the drawback of providing a macroscopic view, involving difficulties in cross-checking the figures given by waste producers and holders and those of the National Inventory.

A detailed description of each waste family in the National Inventory can be found in a separate volume - the Catalogue describing the families of radioactive waste - which provides data for this report.

2.3.2 Preparing statements of existing waste

Existing waste is thus presented by family in the above-mentioned Catalogue. In this report, statements for each category included in the classification of existing radioactive waste by management solution, economic sector and owner can be found in Chapter 3. Chapter 4 also contains statements by activity sector.

2.3.3 Radioactive waste production forecasts

Forecasts for 2020 and 2030

Radioactive waste production forecasts have been made up to two milestone dates: 2020 and 2030 (see Section 2.1.2).

They are based on a production scenario, on a scale representative of the whole nuclear power sector, (the assumptions considered in building this scenario are described in Chapter 3) and on specific assumptions for each activity sector. This is because the types and volumes of radioactive waste produced by the nuclear power industry cannot be forecast without making prior assumptions as to future electricity consumption, the future of nuclear power plants and the spent fuel processing policy, etc. Since the National Inventory accounts for all waste (conditioned and unconditioned) in "conditioned equivalent volume" (see Section 2.3.1), assumptions regarding conditioning modes are also needed to quantify forecasts.

These forecasts are given by family in the Catalogue describing the families. Statements for each category included in the classification of existing radioactive waste by management solution and economic sector can be found in Chapter 3. Chapter 4 also contains statements by activity sector.

Why 2020 and 2030? And then what?

The year 2020 was imposed for earlier inventories (the 2004 and 2006 editions of the National Inventory) because it is the potential decommissioning date for the first nuclear power plants currently in operation, most of which were commissioned between 1980 and 1990. According to EDF, a 40-year service life is now technically feasible given the research and development activities undertaken and the resources committed, especially in connection with studies on the long-term behaviour of materials. Maintenance and investment policy has also been adapted for more effective risk control and optimum use of the latest knowledge of ageing phenomena. Nevertheless, operation of nuclear reactor units by EDF for a period

Most countries have also adopted an inventory system based on a waste family principle. The degree of detail, however, varies from one country to another.

of 40 years, or even longer, as is the case in the United States for facilities designed with similar technology, remains subject to approval by the authorities, in particular when they carry out their ten-yearly, in-depth safety inspections. A standard service life of 40 years has also been assumed in calculations of the impact of plant operating life from the accountancy point of view (depreciation allowances for fixed assets, provisions, etc.).

This edition of the National Inventory has maintained the date of 2020 to provide an intermediate "snapshot".

Beyond this date, future political and energy choices will largely dictate the amounts and types of materials and waste produced by future cycles. In particular, these choices will affect how nuclear power plants may be renewed and to what extent (in 2017, the oldest nuclear power plants will have been in service for 40 years). Choices will also have to be made concerning the back end of the nuclear fuel cycle. In the 2009 National Inventory, forecasts of waste by family beyond 2020 are based on a scenario that assumes continuing operation of nuclear power plants. This scenario is described in Chapter 3.

The year 2030 was chosen in connection with Article 7 of the Act of 28 June 2006, which stipulates that the owners of intermediate-level, long-lived waste produced before 2015 should condition it by 2030 at the latest.

For the sake of uniformity, 2020 and 2030 are the dates chosen for forecasts of radioactive waste originating from all production sectors, not just the nuclear power plant sector but also Research, Defence and non-nuclear industries.

Beyond 2020, future political and energy choices will largely dictate the amounts and types of waste produced by future cycles.

Beyond 2030, the 2009 edition of the National Inventory - like its predecessor - includes an estimation of "committed" waste, which is to say an estimation of the total quantity of waste produced by existing facilities until the end of their life, including waste generated by dismantling operations. As previously mentioned, this type of estimation depends on France's energy policy once existing nuclear power plants have reached the end of their lifetime. The estimations in the Inventory are based on two assumptions: the first is that nuclear power will be abandoned, so no new nuclear power plants will be built, while the second, on the contrary, considers that nuclear power plants will be completely renewed. These are only two of the many possible scenarios. These evaluations should therefore be considered as approximate indications. These estimations and the scenarios that underpin them are described in Chapter 3 and in greater detail in Appendix 2.

The National Inventory steering committee has approved this approach in full, together with the scenarios and main assumptions.

survey of radioactive materials

2.4

In accordance with Article L542-12 of the Environmental Code, as amended by the Act of 28 June 2006, the National Inventory provides a survey of radioactive material.
Many of these substances contain "nuclear materials", i.e. radioactive elements that France accounts for in an inventory, in accordance with its commitments regarding the non-proliferation of militarily sensitive materials (uranium, plutonium, etc.). Each operator tracks the masses of these nuclear materials as part of the "nuclear material accounting" process: this is regularly monitored both by the French and European Union authorities under the terms of the EURATOM treaty. The National Inventory does not seek to take the place of this accounting process, which remains confidential. It simply presents overall figures and makes no claim to offer the same degree of detail as the accounting process mentioned above. Stock evaluations and production forecasts for these materials are based on declarations submitted by producers in the same way as for waste.
This approach meets the objectives set out in the National Radioactive Materials and Waste Management Plan (PNGMDR). Some of these substances could eventually become waste if the public authorities or holders were to consider it unwise to recycle them. Others, if they were to undergo additional treatment, could produce waste. On this subject, the Decree of 16 April 2008 [III] relative to PNGMDR requirements, that the owners of recoverable materials for which recovery processes had never been carried out were to submit to the Ministers for Energy and the Environment, and to Andra, by 31 December 2008 at the latest, a report on the studies of recovery processes under consideration. These reports were submitted at the end of 2008. The aim of the studies is to classify, where necessary, certain materials as waste in the next update of the National Inventory and PNGMDR.

[III] Decree 2008-357 of 16 April 2008 which implements Article L542-1-2 of the French Environmental Code and defines requirements relating to the Plan for the Management of Radioactive Materials and Waste.

2.5 computerised management of data

As of 2008, waste producers and holders have been able to make their declarations online. The introduction of online declarations is a significant improvement in the transmission of information. Information had previously been obtained through electronic files in the case of major producers, or by mail or fax with small-scale nuclear waste producers. The online survey for 2008 has already been set up for the main producers and is gradually being set up for small producers.

Once it has been checked by Andra, all data - whether or not it is declared online - is entered into a computerised database. This base is used to prepare the reports described in Sections 2.3.2 and 2.3.3.

National Inventory verification tools

The strict data gathering, verification and publication procedures used ensure that the National Inventory is of the highest quality, meticulous and reliable.

2.6.1 Verifying the data on stocks at the end of 2007

Declarations submitted by various types of producer:

Major players in the nuclear industry (EDF, AREVA, CEA),
organisations managing several sites. Each site appoints "officers" who are well-acquainted with the state of stocks and who complete the declaration forms. The declarations are then checked and validated by each organisation. The reliability of declarations relies on the producers' internal monitoring systems (verification and validation systems and re-reading for consistency).

Industrial firms or laboratories that produce waste in some other context.
In many cases, these firms already have arrangements with Andra for their waste removal. Andra is in direct contact with appointed officers on each site.

Waste storage and disposal facilities
These sites are basic nuclear installations (INB) or facilities classified for environmental protection. In all cases, they are legally obliged to keep track of the waste received and to make declarations to the authorities responsible. Their inventories are thus identified and under control.

Sites contaminated by radioactivity

One of Andra's tasks is to take part in cleanup operations of contaminated sites at the request of the prefecture. Its knowledge of the sites for which it is responsible allows the Agency to submit its own declarations, which is a guarantee of reliability. For other sites, Andra contacts the site owner or organisation responsible for cleanup.

All declarations are checked then validated by Andra

The Agency checks each detail in the declaration (comparing it with the previous declaration, checking for consistency, cross-checking with any other available sources and examining the management solution that the producer has chosen for the waste). If the declarations need to be corrected in any way, Andra contacts the producer, then validates the corrected data.
Andra is certified ISO 9001, which is the international quality standard.

The data is submitted to the National Inventory steering committee

As mentioned in Section 2.1.3, the steering committee confirms the overall consistency of material and waste volumes.

2.6.2 Verifying scenarios and assumptions

As they refer to the future, the forecasts and assumptions featuring in the National Inventory (forecasts on conditioning methods, future production quantities and developments in radioactive waste production modes) cannot be "verified", strictly speaking. There are other equally valid sets of assumptions and forecasts.
Despite this major drawback, certain provisions guarantee the credibility of these assumptions:

- the scenarios adopted are shared by the various parties involved in waste management;
- all these assumptions have been previously submitted to the National Inventory steering committee.

2.6.3 Other types of information

The National Inventory also contains descriptive data on waste packages, primarily in the Catalogue that groups together the family record sheets (volumes, radioactivity, chemical composition, etc.). This data comes from the producers' technical documents or information available to Andra. It has been re-read by the producers concerned. The data is illustrative and intended to give the reader a good overview of the main characteristics of the waste. It is likely to be changed or expanded with each new edition of the National Inventory.
Lastly, this edition includes, for the first time, information on storage facilities for waste for which no industrial management solution has yet been found (see Section 2.1.1). Thanks to the information it acquires during its waste package monitoring activities, Andra is able to judge the relevance of the data on this subject given in declarations. Chapter 3 and Appendix 4 give information on storage facilities.

3 general findings

3

In all, the 2009 edition of the National Inventory lists 1,121 sites with radioactive waste, as at the end of 2007.

Strict administrative regulations (e.g. for basic nuclear installations, secret basic nuclear installations, facilities classified for environmental protection) govern most of the facilities of radioactive waste producers and holders.

More than 90% of radioactivity is concentrated at two sites, mainly La Hague and, to a lesser extent, Marcoule. Despite the large numbers of "diffuse" nuclear waste producers, also known as "small-scale nuclear activities" waste producers, they only account for a minor proportion of radioactivity in France.

Full details of sites surveyed can be found in a separate document called the Geographical Inventory. A brief description of the main sites, together with a map showing the distribution of sites by activity and by region is given in Chapter 4 of the Synthesis Report.

The rest of this chapter provides an overview of quantities of existing waste as at the end of 2007 (see Subchapter 1.2) and future waste as at the end of 2020 and 2030 (see Subchapter 2.3), broken down according to management solution.

A quantitative account of waste is also included for these different dates, broken down according to the economic sector producing it. Existing stocks of waste as at the end of 2007 are presented by owner.

Forecasts are based on a scenario that assumes the continuing use of nuclear power (described in Subchapter 3.2) and includes specific assumptions for each activity sector (described in full in Chapter 4). Evaluations only concern waste from the operation or dismantling of existing or "committed" facilities[1] as at the end of 2007.

The second part of this chapter presents radioactive materials survey results at previous cut-off dates.

3.1 radioactive waste

Stocks listed as at 31 December 2007 include both conditioned and unconditioned waste in its final form. Most unconditioned waste was produced between 1950 and 1970 and comes from nuclear power facility operators. Although some of it underwent initial conditioning, it often has to be recovered and re-conditioned to meet current standards.

Quantities given in the statements are expressed in "conditioned equivalent volume" (see Chapter 2). This allows all the waste to be accounted for using a single, common unit. Forecast quantities are also expressed in "conditioned equivalent volume".

The statements found in this chapter concern all existing and future radioactive waste, produced in 12 activity sectors defined for the purpose of the National Inventory (see Subchapter 1.3).

Table 3.1 shows the number of sites surveyed in each of these activity sectors at the end of 2007.

1 Construction licence signed by the end of 2007.

Table 3.1: Number of sites[2] identified in the National Inventory (Geographical Inventory) by activity sector

FRONT END OF THE FUEL CYCLE	31
NUCLEAR POWER	26
BACK END OF THE FUEL CYCLE	4
WASTE TREATMENT OR MAINTENANCE CENTRES	8
CEA CIVIL R&D CENTRES	13
RESEARCH CENTRES (EXCLUDING THE CEA)	569
MEDICAL ACTIVITIES	264
MISCELLANEOUS INDUSTRIAL ACTIVITIES	42
NON-NUCLEAR INDUSTRIES USING NATURALLY-OCCURRING RADIOACTIVE MATERIAL	14
RESEARCH, PRODUCTION OR EXPERIMENTATION CENTRES WORKING FOR THE NUCLEAR DETERRENT	11
DEFENCE SITES	106
STORAGE AND DISPOSAL FACILITIES	33

The statements do not take into account:

- **uranium ore mill tailings** (see Subchapter 4.1) found on some former mining sites[3]. The National Inventory lists 19 such sites, plus the ponds of the COMURHEX Malvési plant, making a total of 20 sites used for the final disposal of these tailings.[4]
- **waste in "legacy repositories".**

Most waste located at these sites concerns the "storage and disposal" activity sector (see Subchapter 4.12).

The term "legacy repositories" refers to disposal sites (other than mining sites) containing waste which is not Andra's responsibility.

The following can be distinguished:

- conventional waste disposal sites (there are twelve of these) that have received regular or occasional consignments of waste with an activity level that, in many cases, is just a few Bq/g. In the Geographical Inventory, most of these sites are labelled "hazardous waste disposal facility" or "non-hazardous waste disposal facility" in accordance with the Orders of 30 December 2002 and 19 January 2006. These were previously referred to as "dumps" or "landfill sites". They can be found are in the following localities:
  - Angervilliers, Essonne;
  - Bailleau-Armenonville, Eure-et-Loir;
  - Bellegarde, Gard;
  - Champteusse-sur-Baconne, Maine-et-Loire;
  - Freney (Les Teppes), Savoie;
  - Menneville, Pas-de-Calais;
  - Monteux, Vaucluse;
  - Pontailler-sur-Saône, Côte-d'Or;
  - Saint-Paul-lès-Romans, Drôme.

2 In the Geographical Inventory, major sites are presented in record sheets, while tables are used for the others.
3 The MIMAUSA inventory (memory and impact of uranium mines), which can be consulted (in French) on the website of the Ministry of Ecology, Energy, Sustainable Development and Territorial Planning (www.ecologie.gouv.fr/etat-radiologique-des-sites.html) provides the most exhaustive inventory possible of sites in metropolitan France where uranium ore exploration, extraction and processing activities have taken place.
4 In some cases, the waste disposed of on site does not, strictly speaking, consist of uranium ore mill tailings, but of very-low-level waste from the operation and dismantling of fuel-cycle front-end facilities. These sites were used as dumps for this type of waste in the 1970s and 1980s.

- Saint-Quentin-sur-Isère, Isère;
- Solérieux, Drôme;
- Vif (the Le Serf dump), Isère.

Note: Bellegarde, in the Gard, is the only one of these sites that still receives waste with technically enhanced natural radioactivity, under the conditions set out in the Ministerial Circular of 25 July 2006.

- sites, generally located in the vicinity of nuclear facilities or plants (there are 8 such sites), with mounds, backfills or ponds containing radioactive waste from the past, which the owner or holder did not plan to recover at the time of the National Inventory declaration. These sites are listed below (end of 2007):
  - Pierrelatte mound[5], Drôme;
  - Bugey mound, Ain;
  - former storage facility located under the buildings of the ATOFINA plant in Serquigny, Eure;
  - Vernay lagoon in Loos-Lez-Lille, Nord;
  - La Pallice harbour in La Rochelle, Charente-Maritime;
  - Montboucher mound, Essonne;
  - A87 motorway in Chilly-Mazarin, Essonne;
  - La Rochelle (Chef de Baie plant)[6], a site where solid residue is disposed of in backfill.
- sites in French Polynesia (Mururoa, Fangataufa and Hao), which concern the activity sector "Research, production or experimentation centres working for the nuclear deterrent", where waste from nuclear experiments in the Pacific has been disposed of (see Appendix); these sites are also considered as legacy repositories.

This makes **a total of 23 legacy repositories** in the survey. Twelve of them are conventional waste disposal facilities and three are atolls in French Polynesia.

Note: some mining sites (see top of list) are also disposal sites for very-low-level waste other than uranium ore mill tailings.

- **radioactive substances located at sites where radioactive materials or objects were handled in the past** , which have been "confirmed" and do not need to be cleaned up. Depending on the contamination level, site accessibility and its potential uses, the public authorities may decide whether or not to have a site cleaned up at some future date. If they decide that the site does not need to be cleaned up, there is no induced waste, so the National Inventory does not take it into account. The National Inventory does, however, count (see Chapter 5) (i) sites awaiting cleanup or in the process of being cleaned up, (ii) cleaned-up sites where waste has been stored pending removal, (iii) cleaned-up sites with or without easement (for the record). Waste from sites that have been or are being cleaned up is taken into account in the survey.
- **waste dumped in the Atlantic** in 1967 and 1969 (see Appendix 5).
- **very-short-lived waste,** with a half-life of less than 100 days. This waste is stored on site for radioactive decay before being disposed of using conventional methods. This means that it is not sent to a dedicated radioactive waste repository.

5 Note that AREVA has decided to transfer some of the waste from this mound (diffusion barriers) to an appropriate repository by 2013. Andra has also been contacted to begin investigations into solutions for the other waste. See Subchapter 4.12.

6 This site is part of the activity sector "non-nuclear industries using naturally-occurring radioactive material"; it was not included in the "storage/disposal" activity sector because waste (radium-bearing residues) is still produced there.

These exclusions concern all the statements included in this report. They will not be given any further mention.

3.1.1 Radioactive waste stocks identified as at 31 December 2007

The volume of radioactive waste, identified from the beginning of its production until 31 December 2007 is about 1,153,000 m^3 (conditioned equivalent volume), with all management solutions and sources taken together. By the same date, more than 71% of this volume, i.e. about 824,600 m^3 had been definitively disposed of.

3.1.1.1 Distribution by management solution according to the French classification system

Table 3.2 and Figure 3.1 show the existing volumes of waste found in France as at 31 December 2007, excluding foreign waste defined under Article L542-2-1 of the French Environmental Code[7].

Table 3.2: Volumes of radioactive waste at the end of 2007 in m^3 conditioned equivalent

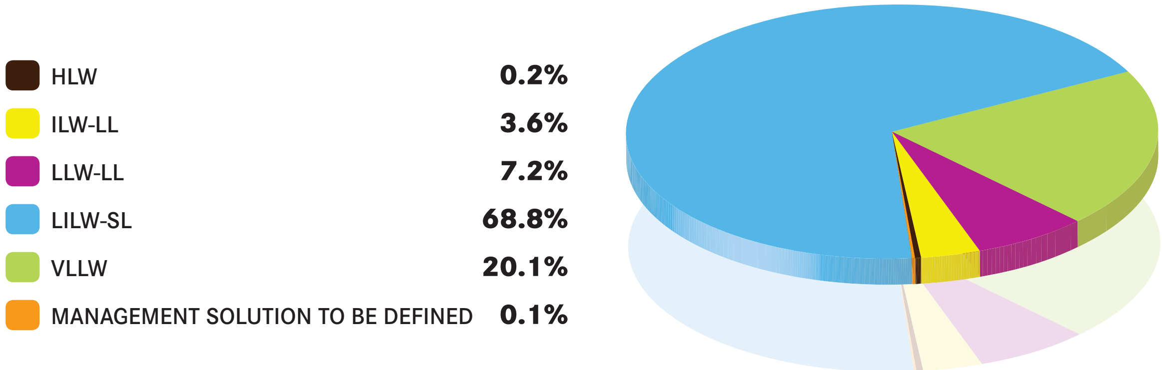
	Volume (m^3)
HLW	2,293 of which 74 is spent fuel[8]
ILW-LL	41,757
LLW-LL	82,536
LILW-SL	792,695 (of which 735,278 is in repositories)
VLLW	231,688 (of which 89,331 is in repositories)
MANAGEMENT SOLUTION TO BE DEFINED[9]	1,564
TOTAL	**1,152,533 (824,609 already in repositories)** meaning **1,150,969** with management solutions

7 See Decree 2008-209 of March 2008 on applicable procedures for the processing of spent fuel and treatment of radioactive waste from abroad.

8 EL4 fuel from the Brennilis heavy-water prototype reactor, fuel from the Osiris research reactor, various experimental fuels, fuels from first-generation, natural-uranium, gas-cooled, graphite-moderated reactors (GCR) still to be processed (see Subchapter 4.5).

9 This waste is no longer included in subsequent statements as it cannot be expressed in "conditioned equivalent volume" units until a conditioning solution has been defined for it.

Figure 3.1: Radioactive waste volumes at the end of 2007, by management solution, in m^3 conditioned equivalent



Waste identified in the "management solution to be defined" category is generally low- or very-low-level waste.

Waste identified in the "management solution to be defined" category is generally low- or very-low-level waste. Operators declare it for National Inventory purposes without assigning it to one of the HLW, ILW-LL, LLW-LL, LILW-SL or VLLW management solutions, either because the waste is in a chemical or physical form that is currently incompatible with an existing or planned management solution, or because no treatment method is contemplated for the time being. The final form that this waste will take once treated and conditioned, and the management solution to which it could eventually be assigned, are either unknown or undeclared at the present time.

This waste includes:
- liquid effluent or sludge that cannot be treated at the moment because of its chemical composition (about 420 m^3); it is located mostly at the FBFC site in Romans (Drôme);
- tritiated distillates (about 100 m^3), located at the CEA site in Saclay (Essonne);
- solvents, organic effluent, contaminated oils and lubricants, (about 200 m^3), located mostly at AREVA's site in Pierrelatte (Drôme);
- "mixed" waste, composed of a mixture of toxic chemical and radioactive contaminated waste (about 400 m^3 of asbestos waste, ion-exchange resins, incineration residue, lead, etc.); most of this is located at the FBFC site in Romans and the former gaseous diffusion plant in Pierrelatte;
- filters (about 60 m^3);
- solid waste to be characterised, stored at the SOGEDEC site in Pierrelatte (26) (about 260 m^3).

Some fluorites resulting from chemical operations on recycled uranium located at the COMHUREX site in Pierrelatte, and which were identified in the 2006 National Inventory as having no management solution, have been assigned by the operator to the VLLW solution for this National Inventory. At the end of 2007, Andra was in the process of examining an application for disposal of this waste at the CSTFA disposal facility (Aube). Acceptance of these fluorites (332 m^3 identified in the 2006 edition of the National Inventory and 355 m^3 in the latest edition) was still under consideration at the end of 2008.

Assumptions and principles on which these volumes are based

Volume calculations are based on a number of assumptions which are described in the Catalogue describing families of waste. The main assumptions are as follows:

- for unconditioned waste, the assumptions considered in the statements with regard to conditioning are the producer's, even if the conditioning solutions in question are still at the design stage and/or if they still need to be validated by the Nuclear Safety Authority or accepted by Andra for disposal;
- waste from dismantling operations is only taken into account if the operation in question had actually been completed by 31 December 2007. For this reason, LLW-LL graphite waste (see Chapter 4) remaining in reactors (stacks, reflectors still in place, support areas) is not included in the stocks at the end of 2007 but is considered according to its production between 2008 and 2030;
- while the study of the management solution for a particular family is in progress, the classification of that family is based on the producer's assumption. Andra checks whether the classification is appropriate (see Subchapter 2.1);
- some of the waste at the La Hague site is to be returned to foreign customers. In this respect, the foreign waste mentioned under Article L542-2-1 of the Environmental Code is not included in the statements. The overall inventory of waste at the La Hague plant, including foreign waste, and showing the share for each state, is given in Subchapter 4.3. Appendix 1 describes how AREVA assigns this waste to each country;
- spent sources, excluding lightning rods (sealed sources, smoke detectors, source rods, source clusters, etc.), belong to a family of their own which is not part of the waste classification system based on management solutions. This National Inventory does not give any conditioned equivalent volume for these sources. The results of the study with which Andra has been entrusted (see Subchapter 1.2 and Box 3.1) on processes for disposing of sources[10] at existing or planned facilities will make it possible to classify these sources by management solution and estimate their conditioned equivalent volume.This will be small compared with most of the waste familes in the Inventory.

Volume calculations are based on a number of assumptions which are described in the Catalogue describing families of waste.

10 Including lightning rods, which the National Inventory accounts for in two specific LLW-LL families.

Box 3.1:

Study on the sustainable management of spent sealed radioactive sources assigned to Andra under the Act of 28 June 2006

In accordance with the Act of 28 June 2006, Andra submitted its study on the sustainable management of spent sealed sources at the end of December 2008. The study defined a method for classifying spent sealed sources into categories based on existing management solutions (CSTFA, CSFMA) and future solutions (LLW-LL, HLW, ILW-LL), in view of their half-life, activity level and dimensions. The method was then applied to the detailed inventory of sources, carried out in cooperation with the holders of the sources.

Spent sealed sources are extremely varied in terms of the radionuclides they contain, activity levels, forms, etc. This diversity is reflected in the inventory, which covers some 2 million sources.

Compared with other types of waste at disposal facilities, a sealed source can lead to additional exposure risks, induced by its physical and mechanical properties. There is a risk that any unauthorised persons entering the repository, quite unaware of the dangers involved, might wish to remove the source simply because it is small and light and catches their eye.

Taking this into consideration, the inventory of spent sealed sources was built around a number of important disposal parameters. Five groups of sources incorporating solid radioactive substances are identified. The sources in each of these groups are assigned to the most suitable disposal solutions.

The study concludes that around 83% of the two million sources covered by the inventory are compatible with near-surface disposal, 15% with surface disposal, and 2% with deep disposal.

Most processes to be implemented in preparation for disposal involve removing the equipment that contains the sources, then conditioning the sources according to the disposal solution adopted (most spent sealed sources are not conditioned at present).

Spent sealed sources are extremely varied in terms of the radionuclides they contain, activity levels, forms, etc. This diversity is reflected in the inventory, which covers some two million sources.

Changes - comparison with volumes given in the 2006 National Inventory

Changes in volumes are primarily due to the operation of facilities during 2005, 2006 and 2007; the quantities of waste produced over these three years are added to existing stocks. Other reasons, however, can account for these changes, which are not always synonymous with increases. These are described individually for each National Inventory family in the Catalogue describing the families of radioactive waste.

A summary of the main changes observed for each management solution is given here.

HLW (High-Level Waste) management solution

The HLW stock at the end of 2007 includes (i) in-process vitrified waste packages and old fission product solutions from the La Hague site awaiting vitrification, (ii) old vitrified waste packages from the Marcoule site (iii) certain types of spent fuel (EL4 fuel from the Brennilis heavy-water prototype reactor, CEA research fuels, etc.) not destined for processing (see Chapter 4) and which are therefore counted as waste.

Overall, the stock of vitrified waste packages or those intended for vitrification is as expected. The unprocessed spent fuel described above was accounted for as radioactive material in the 2006 National Inventory.

ILW-LL (Intermediate-Level, Long-Lived Waste) management solution

Notwithstanding three additional years of production, the volume of ILW-LL stock at the end of 2007 was about 9% lower than that observed at the end of 2004 for the 2006 National Inventory.

This decrease can largely be explained by:

- changes in reconditioning planned for the 26,131 drums of ILW-LL bituminised waste produced before 1996 at the Marcoule site[11]. As a result of the new conditioning, the volume of this waste has fallen by 3,000 m^3 for the same number of drums;
- conditioning the sludge produced by the activities of the La Hague UP2-400 plant before 1991 and stored in seven silos at the former effluent treatment station (STE2). According to the 2006 National Inventory, all this sludge was to be embedded in a bitumen matrix. In 2007, however, only some of the sludge from one silo (silo 14) had been bituminised, producing 340 drums. Since then, the Nuclear Safety Authority has declared that this STE2 sludge must not be bituminised in the STE3 facility. AREVA is looking into alternative conditioning solutions for the unbituminised sludge remaining in silo 14 and for the contents of the other silos. One of these alternatives, considered in this National Inventory (see the Catalogue describing the families of radioactive waste), reduces the total conditioned equivalent volume by more than 2,000 m^3;
- revised production ratio for packages of hulls and end caps in CSD-C (standard compacted waste) containers at the La Hague site. Feedback on production between 2005 and 2007 has shown that this type of conditioned waste represents a smaller proportion of total waste than was assumed in the 2006 National Inventory. The vast majority of hulls and end caps included in stocks at the end of 2004 in the 2006 National Inventory had not yet been compacted and conditioned as CSD-C packages, but stored underwater in temporary containers awaiting recovery. This explains the drop in conditioned equivalent volume between this National Inventory and the 2006 edition.

Other changes observed in the conditioning assumptions made by waste producers can lead to decreased or increased volumes. For example, EDF now makes the assumption that activated waste from its reactors will be conditioned by cutting it up and cementing it in concrete packages called C1PG packages, either at the future ICEDA facility (activated waste conditioning and storage facility), in the case of operating waste, or directly on site in the case of waste from dismantling operations. This assumption is different from that made in the 2006 National Inventory (waste conditioned in CSD-C stainless steel container) and results in a reduced conditioned equivalent volume for this category of waste.

11 7,000 drums have been or will be reconditioned in 380-litre drums. The remaining drums are reconditioned in 223-litre drums in this National Inventory, whereas the 2006 edition considered that all drums would be reconditioned in 380-litre overpack drums.

LLW-LL (Low-Level, Long-Lived Waste) management solution

An increase of more than 70% was observed in the volume of low-level, long-lived waste at the end of 2007 compared with the stocks reported in the 2006 National Inventory for the end of 2004. This was in spite of the fact that a) very little radium-bearing waste and no graphite waste[12] was produced between 2005 and the end of 2007 and b) more than 6,000 m^3 of rubble from the CEA's Le Bouchet site, known as the "CEA Itteville site", formerly classified in this management solution category, was redirected to the VLLW solution.

There are two main explanations for this significant increase:

- the lower tonnes/m^3 ratio for conditioned graphite waste compared with the 2006 National Inventory. This is because studies conducted in 2006/2007 on the disposal of this category of waste led to different conditioning ratios being adopted from those assumed in the previous edition of the National Inventory;
- inclusion in this management solution of 31,894 drums of bituminised waste produced before October 1996 at the Marcoule site, representing around 33,000 m^3 (conditioned equivalent volume). The assignment of 31,894 drums of bituminised waste to the LLW-LL management solution is currently being studied (the possibility of increasing this number to 40,000 (by adding to these 31,894 drums another 8,106 drums assigned in this Inventory to the ILW-LL category) will be examined in light of the results of the ongoing study). In the 2006 National Inventory, 34,456 drums were accounted for in the LILW-SL solution. At the time the declaration was submitted for this National Inventory, a study was in progress to determine whether they could be disposed of at the Aube LILW disposal facility. In 2006, Andra refused to accept 31,894 of these drums at the LILW facility. Of the remaining 2,562 drums, 258 were accepted under an existing agreement, while an acceptance application has been filed for the other 2,304[13].

LILW-SL (Low- and Intermediate-Level, Short-Lived Waste) management solution

Notwithstanding three additional years of production, the volume of LILW-SL stock at the end of 2007 was slightly lower (by about 1%) than that observed for the end of 2004 in the 2006 National Inventory.

The reason for this decrease is the option (currently under examination) to assign to the LLW-LL category 31,894 drums of bituminised waste that were included in the LILW-SL category in the 2006 edition of the National Inventory (see above).

Other changes have also led to a drop in the volume of stocks for this category, albeit to a lesser degree. One example is the inclusion of EDF operating and dismantling waste in the VLLW category.

VLLW (Very-Low-Level Waste) management solution

Making allowance for the 6,000 m^3 of rubble from the CEA's Le Bouchet site, transferred from the LLW-LL category in the 2006 National Inventory to the VLLW category in this edition, the volume of VLLW at the end of 2007 is as expected.

12 The only graphite waste produced comes from the dismantling of the stacks and reflectors of former natural-uranium, gas-cooled, graphite-moderated reactors (GCR in the rest of this document). None of this dismantling work began between 2005 and 2007.

13 1,952 of these 2,304 drums had been given provisional acceptance at the LILW disposal facility (CSFMA) by mid-2008.

3.1.1.2 Distribution of waste by French owner and by economic sector at the end of 2007

Distribution of waste by owner

Figures 3.2 to 3.8 show the distribution of waste by French owner and for each management solution at the end of 2007.

In the 2006 National Inventory, waste distribution was based on (i) the results of specific studies on HLW and ILW-LL carried out by producers at the National Inventory steering committee's request, (ii) evaluations made by Andra using data available at that time on the other categories of waste. These distributions are now based on the declarations made by waste producers and Andra (for the waste already disposed of at its facilities) for all management solutions. This new approach can account for some of the changes observed in the graphite LLW-LL and LILW-SL categories.
For the HLW, LLW-LL, LILW-SL and VLLW categories, these distributions are based on quantities expressed in terms of conditioned equivalent volumes existing at the end of 2007 (Table 3.2). The figure given for the ILW-LL category in Table 3.2 excludes waste defined under Article L. 542-2-1 of the Environmental Code[14] but takes into account waste packages for which AREVA has transportation rights under certain contracts (see Appendix 1). The ILW-LL distribution by French owner is based on a volume of 41,217 m^3, which does not take this waste into account (waste packages produced as a result of the internal treatment of radioelements conditioned in bitumen drums, standard CSD-B packages or C5 packages).

- **HLW and ILW-LL (Figures 3.2 and 3.3)**
  There is little change compared with the distribution given for HLW and ILW-LL management solutions in the 2006 National Inventory.

In the case of intermediate-level, long-lived waste, this distribution is still subject to uncertainties, especially regarding:
- the detailed assignment of each waste family under contractual agreements between producers still to be finalised;
- conditioning assumptions concerning legacy waste that are still subject to change.

Uncertainties concerning ILW-LL, expressed as a percentage, will be cleared as recovery programmes for this legacy waste are implemented.

EDF owns most of the waste coming directly from the spent fuel that it had processed at the Marcoule and La Hague sites, first by the CEA, then by COGEMA as of 1976 (the year it was created). The first spent fuel from gas-cooled reactors, however, was handed over to the CEA for its civil activities. The CEA therefore remains the owner of waste resulting directly from these activities after processing, primarily at the Marcoule site but also at La Hague. AREVA owns waste from fuel processed under contracts signed before 1977 and which made no provision for the reshipment of waste (512 tonnes of spent fuel out of a total of 10,000 tonnes of foreign spent fuel processed at the La Hague site).

14 CSD-V and CSD-C packages.

Legacy and present waste resulting from defence-related activities at the Marcoule site belongs to the CEA's Military Applications Division (CEA/DAM).

EDF, the CEA's civil research divisions and its Military Applications Division and AREVA also own the intermediate-level, long-lived waste resulting from the operation of their own facilities.

Figure 3.2: Distribution of HLW by volume and by French owner at the end of 2007

EDF share	**72.4%**
CEA/DAM share	**10.3%**
CEA/CIVIL share	**9.6%**
AREVA share	**7.7%**

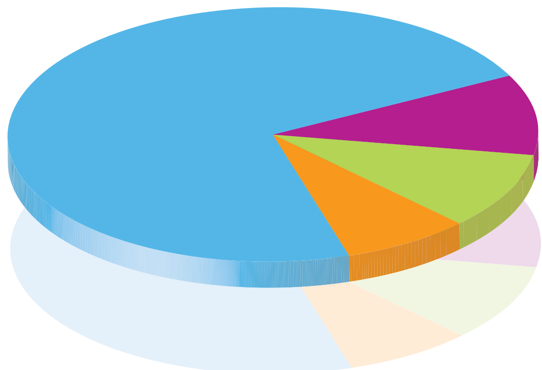
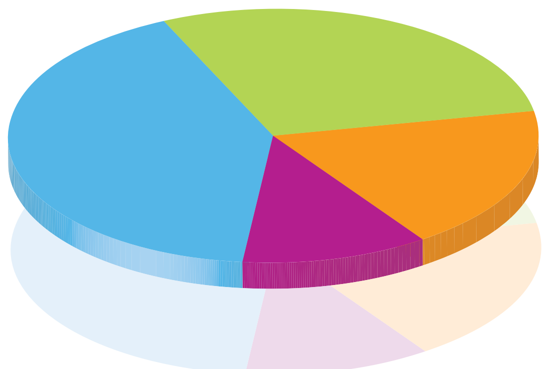


Figure 3.3: Distribution of ILW-LL by volume and by French owner at the end of 2007

EDF share	**41.4% +/-1**
CEA/CIVIL share	**28.9%**
AREVA share	**18.5% +/-1**
CEA/DAM share	**11.2%**



- **LLW-LL (Figures 3.4, 3.5 and 3.6)**
Distributions of graphite waste, radium-bearing waste and other low-level, long-lived waste by owner are shown separately. Expressed in terms of conditioned equivalent volume, graphite waste at the end of 2007 represents a volume of 18,676 m^3, radium-bearing waste 30,450 m^3 and other LLW-LL 33,408 m^3.

As indicated in Subsection 3.1.1.1, graphite waste that is still inside reactors (stacks, reflectors in place, support areas) is not included in stocks at the end of 2007. Consequently, the distributions below only allow for graphite waste that has already been removed from the plants (in particular, the sleeves making up the structure of GCR fuels treated at La Hague and Marcoule).

The main reason for the change in the distribution of radium-bearing waste by owner is that more than 6,000 m^3 of rubble from the CEA's Le Bouchet site (see Subsection 3.1.1.1), considered as low-level, long-lived radium-bearing waste in the 2006 National Inventory, is classified as VLLW here.

Lastly, waste considered in the "other LLW-LL" distribution consists mainly of drums of bituminised legacy waste from Marcoule[15] (see Subsection 3.1.1.1), which was included in the LILW-SL category in the 2006 National Inventory, as well as lightning rods containing radium and americium.

15 The inclusion of this bituminised waste in the LLW-LL management solution is currently being studied.

Figure 3.4: Distribution of graphite waste by volume and by owner at the end of 2007

EDF share	**69.6%**
CEA/CIVIL share	**16.9%**
AREVA share	**11.7%**
CEA/DAM share	**1.8%**

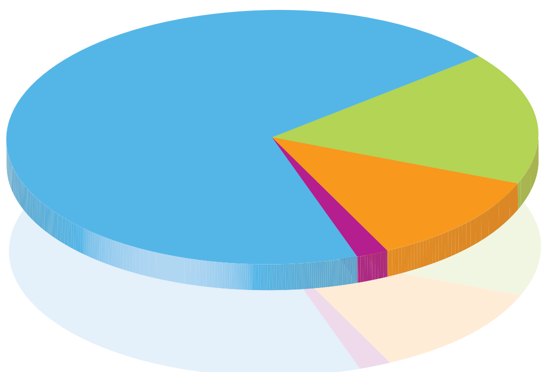


Figure 3.5: Distribution of radium-bearing waste by volume and by owner at the end of 2007

RHODIA share	**43.3%**
CEA/CIVIL share	**39%**
Others	**11.4%**
AREVA (CEZUS) share	**6.3%**

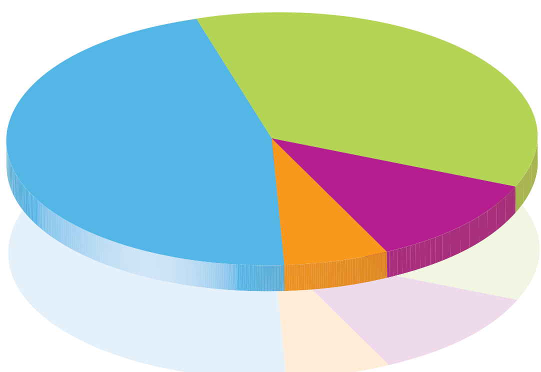
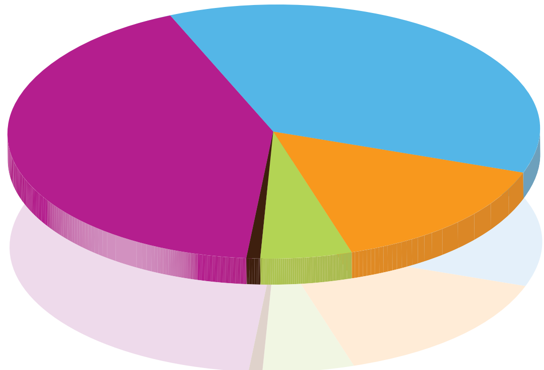


Figure 3.6: Distribution of other LLW-LL by volume and by owner as at the end of 2007

CEA/DAM share	**39.8%**
EDF share	**39.3%**
AREVA share	**14.7%**
CEA/CIVIL share	**5.6%**
Others	**0.6%**



LILW-SL and VLLW (Figures 3.7 and 3.8)

LILW-SL and VLLW from a given site generally belongs to the operator of the site in question.

The inclusion of 31,894 drums of bituminised legacy waste from Marcoule in the LLW-LL category (the option currently being studied) has little impact on the distribution given in the 2006 edition of the National Inventory, in which these drums were accounted for in the LILW-SL category. Most of the differences observed in this distribution are due to the new method used to calculate the shares of each owner described above.

Lastly, 6,000 m^3 of rubble from the CEA's Le Bouchet site, considered in the 2006 National Inventory as radium-bearing waste, is now included in the VLLW category, leading to a significant difference in the distribution of VLLW by owner.

Figure 3.7: Distribution of LILW-SL by volume and by owner as at the end of 2007

EDF share	**47.4%**
CEA/CIVIL share	**20.7%**
AREVA share	**20.5%**
CEA/DAM share	**5.9%**
Others	**5.5%**

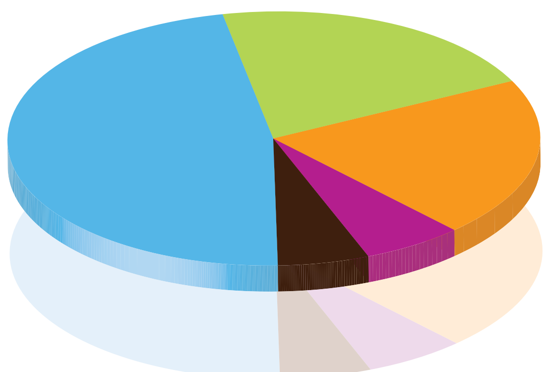
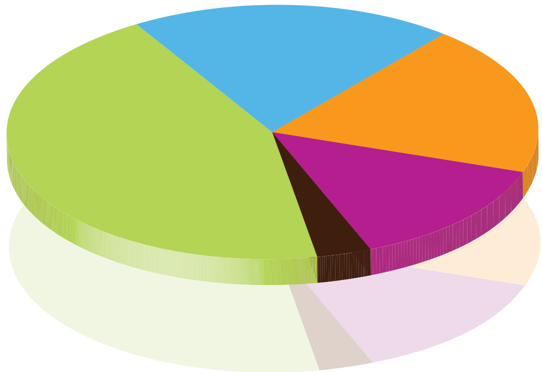


Figure 3.8: Distribution of VLLW by volume and by owner as at the end of 2007

CEA/CIVIL share	**44.2%**
EDF share	**19.7%**
AREVA share	**19.2%**
CEA/DAM share	**13.8%**
Others	**3.1%**



Distribution by economic sector

The distribution of radioactive waste by economic sector (see Subchapter 1.3) is shown for each management solution in Figures 3.9 to 3.13.
Andra has based its estimation of this distribution chiefly on the distribution by owner shown above.

The waste included in the **Nuclear Power** sector comes from the activities associated with nuclear power plants, fuel-cycle front-end facilities and spent fuel processing plants. Most waste assigned to the HLW, ILW-LL and LILW-SL management solutions comes from this economic sector. Low-level, long-lived waste produced by CEZUS in the manufacture of zirconium sponges for the nuclear industry is also included in this category (see Subchapter 4.9).

High-level and intermediate-level, long-lived waste assigned to the **Defence** economic sector belongs to the CEA's Military Applications Division (CEA/DAM). This economic sector also includes other waste produced by CEA/DAM, but assigned to other management solutions, as well as various categories of waste from defence-related activities (DGA, SSA, Army/Air Force/Navy, Gendarmerie facilities).

The **Research** economic sector mostly concerns waste produced by the CEA's civil research activities. A smaller proportion comes from research carried out at centres outside the CEA. Non-CEA research centres include, for example, the European Organisation for Nuclear Research (CERN), the Laue Langevin Institute[16], GANIL, the large-scale, heavy-ion accelerator, and the French National Institute of Nuclear Physics (IPN) in Orsay. By convention, radium-bearing waste resulting from the cleanup of the former uranium ore processing plant, run by the CEA between 1946 and 1970, is included in this economic sector.

Waste produced by companies using naturally radioactive materials[17], including, in particular, RHODIA, which extracts rare earth elements, are included in the **Industry apart from nuclear power** economic sector. Other waste in this economic sector is due to the past and present industrial activities of many small companies. This concerns, for example, lightning rods with radioactive tips, manufactured between 1932 and 1986, which Andra has gradually removed and collected. These are included in

16 The Laue Langevin Institute operates the high-flux research reactor (RHF), which has been in use since 1971 as a source of neutrons for scientific research.

17 Except for CEZUS waste, which is in the nuclear power economic sector.

the radium-bearing LLW-LL category. It can be observed that 0.3% of intermediate-level, long-lived waste in the "industry apart from nuclear power" economic sector concerns "source blocks" containing spent sealed sources collected from "small-scale nuclear activities" waste producers in the 1970s and 1980s.

Lastly, the **Medical** economic sector concerns waste from medical therapeutic and diagnostic activities as well as from medical research, much of which is collected by Andra.

Figure 3.9: Distribution of HLW by volume and by economic sector as at the end of 2007

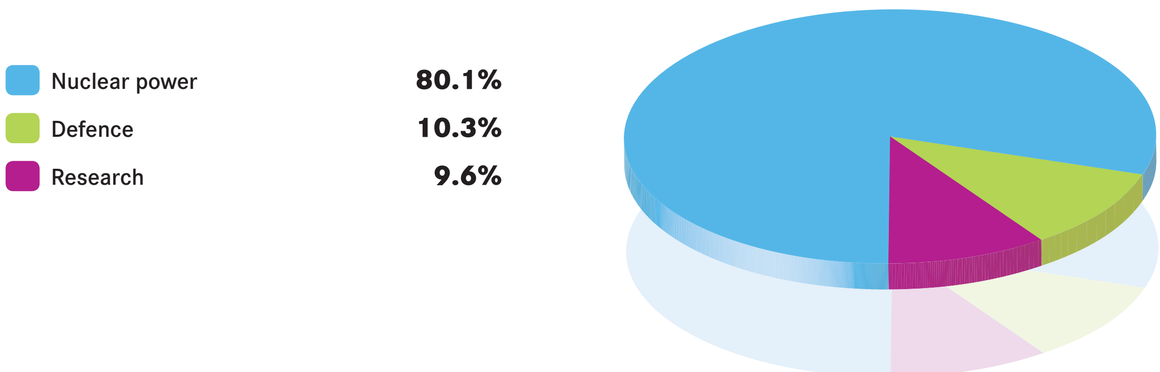


Figure 3.10: Distribution of ILW-LL by volume and by economic sector as at the end of 2007

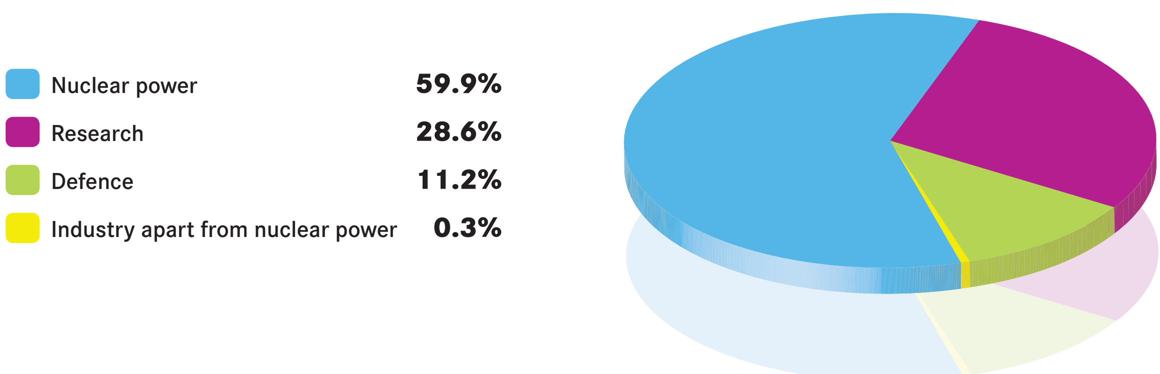


Figure 3.11: Distribution of LLW-LL by volume and by economic sector as at the end of 2007

Nuclear power	**42.6%**
Research	**20.5%**
Industry apart from nuclear power	**20.4%**
Defence	**16.5%**
Medical	**0.03%**

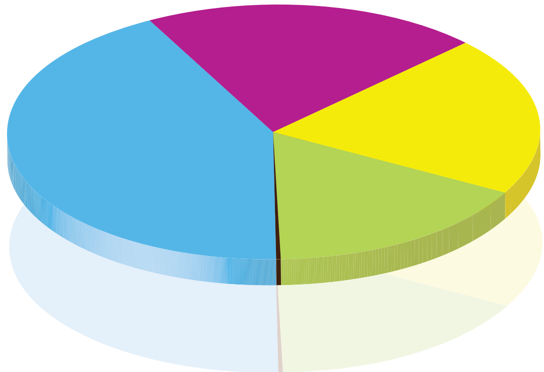


Figure 3.12: Distribution of LILW-SL by volume and by economic sector as at the end of 2007

Nuclear power	**69.4%**
Research	**19.1%**
Defence	**8.1%**
Industry apart from nuclear power	**2.4%**
Medical	**1%**

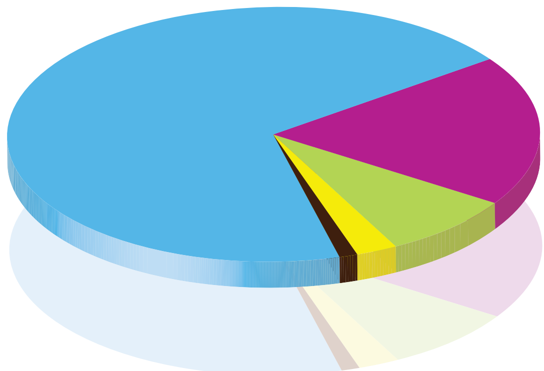
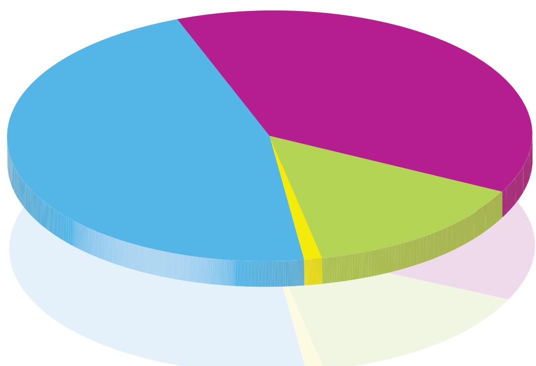


Figure 3.13: Distribution of VLLW by volume and by economic sector as at the end of 2007

Nuclear power	**44.8%**
Research	**39.5%**
Defence	**14.7%**
Industry apart from nuclear power	**1%**



3.1.1.3 Radiological content of existing radioactive waste

Inventory

The inventory of radioactivity contained in waste is compiled from data relating to each family of waste – number of waste packages and mean radioactivity per waste package (see Catalogue describing the families of radioactive waste). These estimates come with a brief calculation of radioactive decay according to the half-life of the radionuclides present, up to 2007 then up to 2030. Radiological content is estimated on the basis of three types of data: alpha radiation, short-lived beta-gamma radiation and long-lived beta-gamma radiation.

Waste producers use different methods to evaluate radiological content:

- **HLW and ILW-LL management solutions:** at Andra's request, producers prepare "descriptive catalogues" that are used in studies of disposal solutions for this type of waste. Radioactivity estimations for legacy waste are less accurate and will be refined once the waste has been recovered.
- **LLW-LL management solution** (graphite or radium-bearing waste): determining the level of radioactivity is based on the results of the analyses carried out on samples and, if necessary, additional assessments declared by the waste producer to Andra. The current knowledge of radioactive content should improve, since Andra now asks for descriptive catalogues for this type of waste to carry out disposal studies.
- **LILW-SL and VLLW management solutions:** producers declare to Andra each waste package sent to disposal facilities using a method involving measurements and/or calculation-based assessments. Andra checks waste compliance before authorising disposal. Apart from a few exceptions[18], radioactivity assessments are based on these declarations, which date back to the time the facilities were commissioned.

The radioactivity of all waste produced as at 31 December 2007 is shown in the following table.

18 Packages not yet accepted at the LILW disposal facility (CSFMA).

Table 3.3: Radioactivity of all waste produced as at 31 December 2007 (values expressed in TBq, i.e. 10^{12} Bq)

	Alpha	Short-lived Beta-Gamma	Long-lived Beta-Gamma
HLW	5,490,000	84,400,000	263,000
ILW-LL	15,900	4,000,000	713,000
LLW-LL	233	7,200	812
LILW-SL	783	19,350	6,060
VLLW	0.9	1.8	0.2

- **high-level waste (HLW)** accounts for 94.98% of the total radioactivity of radioactive waste produced as at 31 December 2007. It consists of waste extracted from spent fuel (fission products and minor actinides produced in reactors). The main radionuclides that contribute to this activity are:

- for alpha radionuclides: curium-244, americium-241;
- for short-lived beta-gamma radionuclides: caesium-137, strontium-90, prometheum-147, caesium-134;
- for long-lived beta-gamma radionuclides: samarium-151, nickel-63, technetium-99.

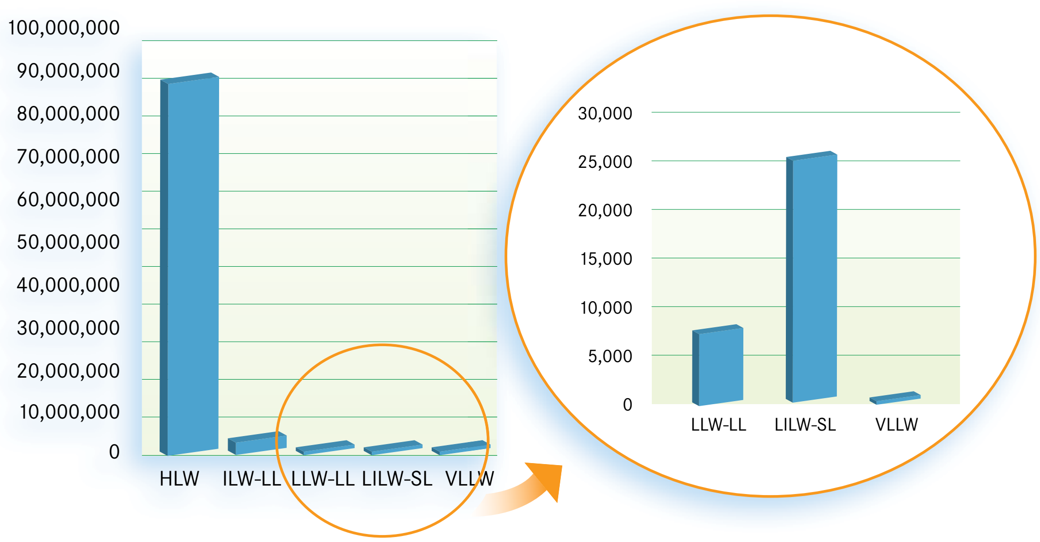
- **intermediate-level, long-lived waste (ILW-LL)** accounts for 4.98% of total radioactivity. Most of the beta-gamma radioactivity in this category is due to activated waste from reactors and nuclear fuel cladding waste (hulls and end caps). The main radionuclides concerned are iron-55, cobalt-60, caesium-137 and strontium-90 for the short-lived and nickel-63 for the long-lived radionuclides.

- **low-level, long-lived waste (LLW-LL)** accounts for 0.0087% of total radioactivity. Graphite waste chiefly contains beta-gamma radionuclides, tritium and cobalt-60 for the short-lived and carbon-14, nickel-63 and chlorine-36 for the long-lived radionuclides. Radium-bearing waste contains natural alpha-emitting radionuclides (radium, thorium, uranium) for the most part.

- **low- and intermediate-level, short-lived waste (LILW-SL)** accounts for 0.0276% of total radioactivity. Much of the beta-gamma share of the activity comes from two families of waste. These are EDF's concrete packages containing ion-exchange resins that have been used to purify reactor coolants, and the concrete packages containing solid maintenance waste such as irradiating filters. Waste from EDF plants contains few alpha-emitting radionuclides. Most of these radionuclides come from conditioned waste from spent fuel processing plants and, to a lesser extent, from research and production centres working for the nuclear deterrent.

Figure 3.14 illustrates this distribution of radiological activity as at the end of 2007.

Figure 3.14: Distribution of radiological activity as at the end of 2007 in TBq, i.e. 10^{12} Bq



The total radioactivity of the waste packages decays according to the half-life of each of the radionuclides that make it up.
After a few centuries, only the "long-lived" component, i.e. the component made up of radionuclides with a half-life exceeding 31 years, remains.

Radioactive decay of the waste

The total radioactivity of the waste packages decays according to the half-life of each of the radionuclides that make it up. After a few centuries, only the "long-lived" component, i.e. the component made up of radionuclides with a half-life exceeding 31 years, remains.

The following two curves (Figures 3.15 and 3.16) illustrate the change in total radioactivity, expressed in terabecquerels (TBq, i.e. thousands of billions of becquerels) over the first thousand years, per average vitrified waste package produced at La Hague. The decay of caesium-137 and strontium-90, which are short-lived elements, predominates.

Activity has not completely disappeared after 1,000 years. It has simply decayed by a factor of over 100 and is equal to the sum of activity levels of the long-lived elements, which is less than 100 TBq. Another way of representing the change in activity must be adopted to observe this residual activity, using a graph where the axes conform to a logarithmic scale, in other words, that "highlight" short times and the lowest activity levels.

Radioelement decay causes the thermal power of the waste package (i.e. the heat it gives off) to decay. This value drops from an average of 1,900 watts per package at the time of production to 500 W after fifty years and to about 1 W after 10,000 years.

Figure 3.15: Change in the activity of vitrified waste over the first thousand years

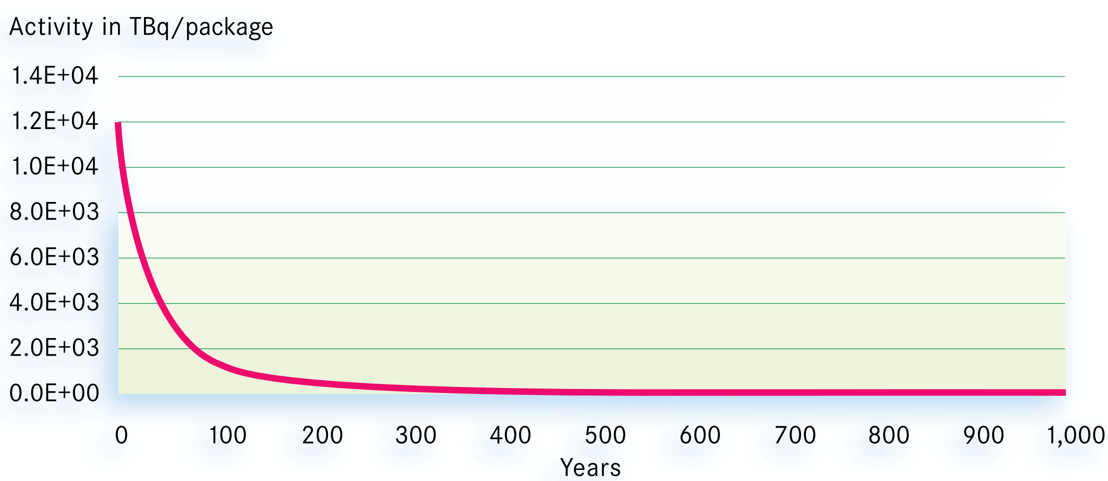
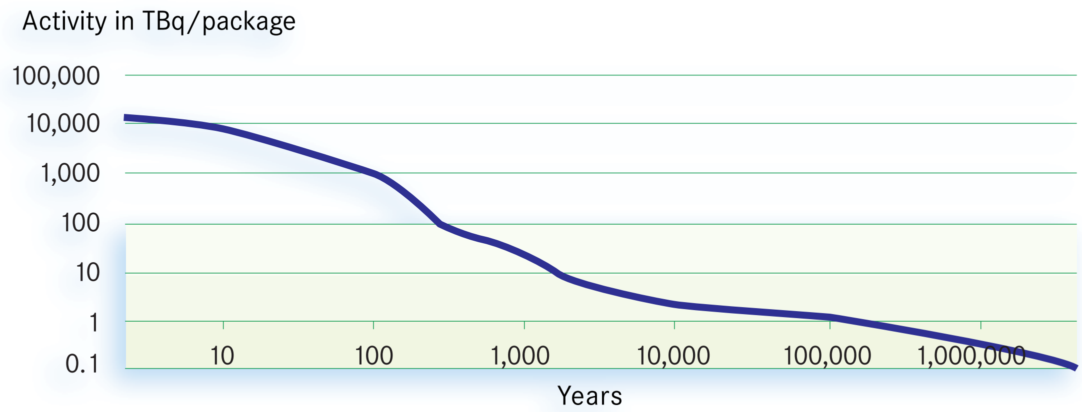
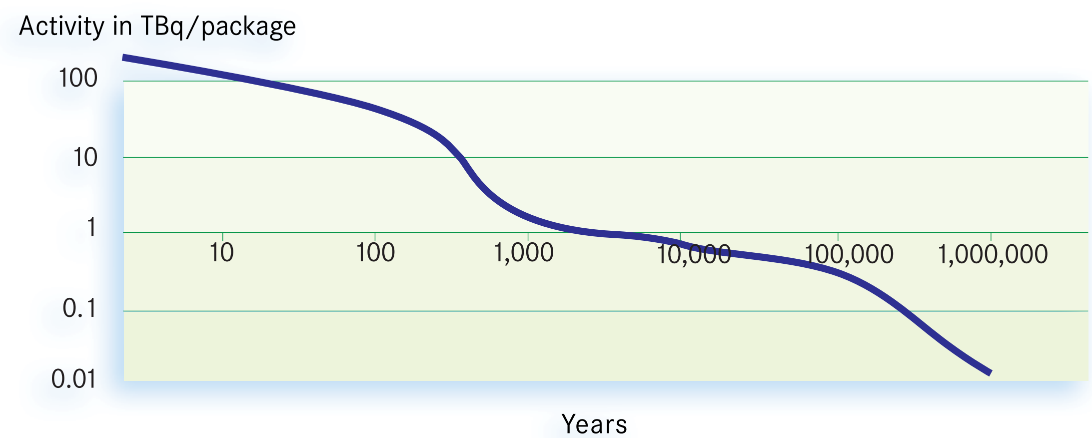


Figure 3.16: Change in the activity of vitrified waste over a million years (logarithmic scale)



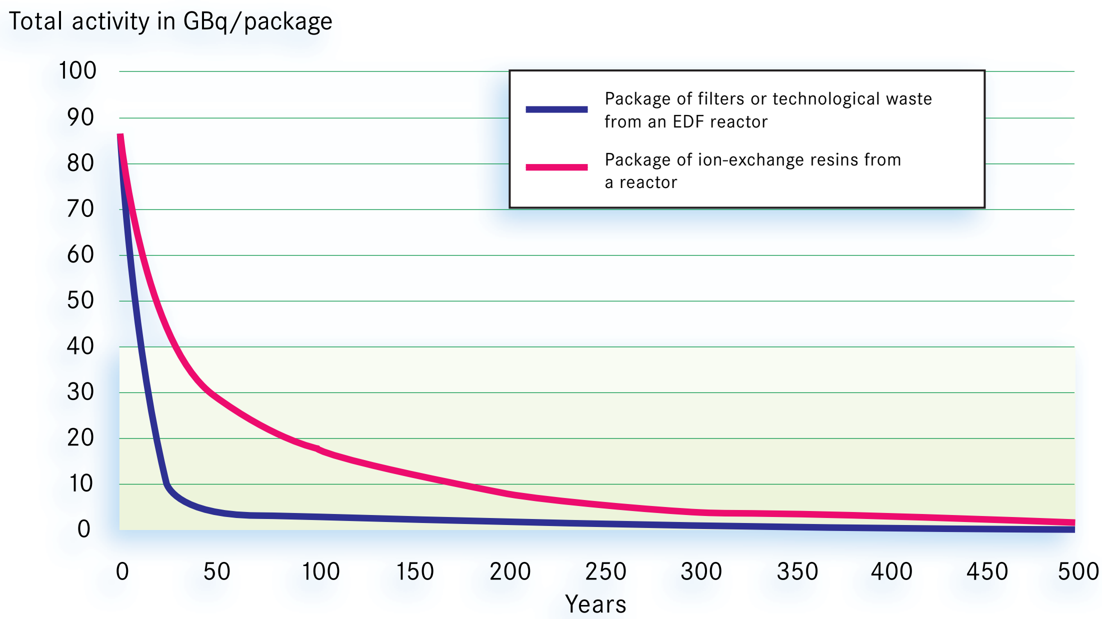
Other illustrations can be given of the radioactive decay of waste packages. For ILW-LL, such as a package of compacted "cladding waste", the curve generally resembles that of glass, (Figure 3.17), although, of course, the initial activity level is lower. The average thermal power of this type of waste begins at about twenty watts per waste package and decays by a factor of 10 in 100 years.

Figure 3.17: Change in the activity of an average package of compacted spent fuel cladding waste



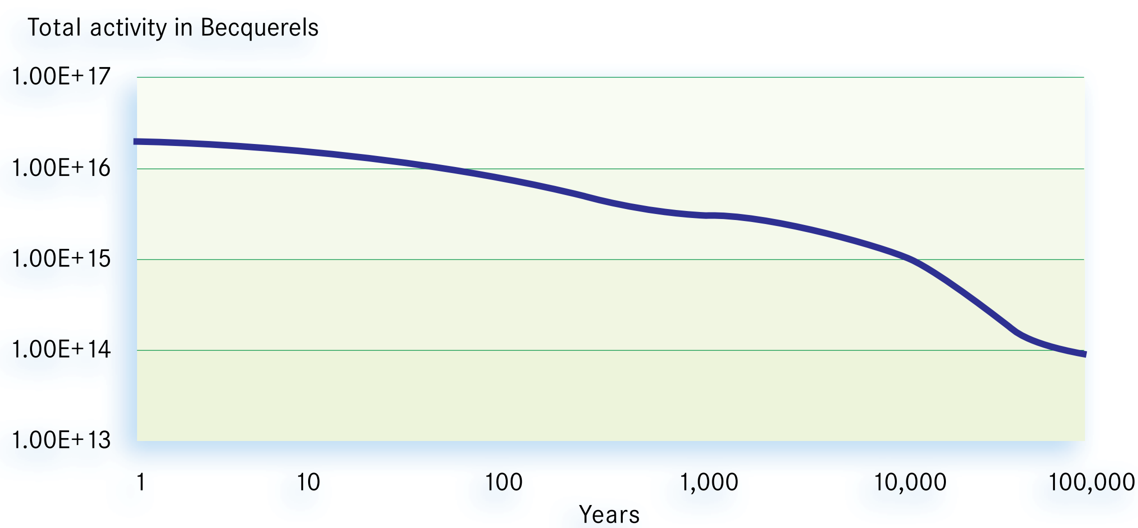
Decay is much faster for an LILW-SL package. Figure 3.18 illustrates the example of decay in two representative waste packages delivered to the CSFMA low- and intermediate-level waste disposal facility (Aube)) by EDF. This time the activity is measured in gigabecquerels (GBq or billions of becquerels) per waste package. In both cases it is divided by more than ten in three hundred years. The thermal power of these waste packages is negligible.

Figure 3.18: Change in the activity level of two types of LILW-SL package



Lastly, Figure 3.19 illustrates the change in activity for all graphite LLW-LL (including waste from reactors that had not been dismantled at the end of 2007). Owing to the presence of carbon-14 and chlorine-36, which are respectively long- and very-long-lived elements, activity will have decreased by more than a factor of 100 after 100,000 years.

Figure 3.19: Change in the activity level of graphite waste



3.1.1.4 Management of existing waste: conditioning and long-term future

Conditioning as at 31 December 2007

Radioactive waste can only be placed at a storage or disposal facility if its characteristics meet acceptance criteria. Producing the final conditioned form of the waste package is an important stage in waste management.

Conditioning involves different steps and types of operation that not only depend on the operating modes of each company, but also vary over time.

For the purposes of the National Inventory, the different stages of the conditioning process are defined as follows:

- **unconditioned waste:** waste which is not in a container on the date considered (e.g. liquid effluent in tanks, waste in silos, etc.), or which has been conditioned on a temporary basis;
- **preconditioned waste:** waste which has undergone partial treatment/conditioning that will be incorporated into the final package (e.g. a metal drum that will be placed in a concrete package *a posteriori*);
- **conditioned waste:** waste contained in the final package.

Preconditioning and conditioning thus represent two different stages in the conditioning process for the National Inventory. This distinction is not made in the Act of 28 June 2006, which puts preconditioned waste in the same category as conditioned waste.

Table 3.4 shows the distribution of unconditioned, preconditioned and conditioned waste as at the end of 2007.

More than 84% of waste is already in its final conditioned form. Stocks that are not yet in their final conditioned form break down as follows:

- **a marginal amount of HLW.** This consists of fission product solutions that will be vitrified at AREVA's facilities at La Hague and at the CEA's Marcoule site. These include fission product solutions from natural-uranium, gas-cooled, graphite-moderated reactor (GCR) fuels, which require a special "cold-crucible" vitrification process (to make "uranium-molybdenum" or UMo glass);
- **some 51% of ILW-LL.** Most of this is legacy waste that has been stored at the industrial producers' facilities (CEA Cadarache and Marcoule and AREVA La Hague) awaiting deep disposal. It will have to be recovered and conditioned. The Act of 28 June 2006 stipulates that owners of intermediate-level, long-lived waste produced before 2015 must condition it by 2030;
- **a small amount of LILW-SL.** This is either awaiting treatment or is legacy waste;
- **about 90% of LLW-LL.** Radium-bearing waste is stored as is until it can be disposed of at a near-surface repository; this could involve treating it and specifying a suitable conditioning solution.

Graphite waste is stored in decommissioned reactors or in silos.

More than 84% of waste is already in its final conditioned form.

Andra and waste producers are conducting research to find a conditioning solution for graphite waste, based on the use of a 5 or 10 m^3 reinforced-concrete or fibre-reinforced concrete package for direct disposal.

Table 3.4: Distribution of conditioned, preconditioned and unconditioned waste as at the end of 2007 (in m^3 conditioned equivalent)

	Conditioned waste *Volume*	Preconditioned waste *Forecast volume after conditioning*	Unconditioned waste *Forecast volume after conditioning*	Total volume
HLW	2,050	1	242	**2,293**
ILW-LL	20,499	7,880	13,378	**41,757**
LLW-LL	8,137	33,668	40,731	**82,536**
LILW-SL	746,410	7,117	39,168	**792,695**

VLLW is excluded from this count. Simplified conditioning (in big-bags or container boxes) is authorised for acceptance at the CSTFA disposal facility (Aube) for this very-low-level waste. For some waste in this category, no distinction is made between conditioned and unconditioned waste.

Long-term management

Some 129,500 m^3 of radioactive waste, representing 11% of the total amount accounted for as at 31 December 2007, is currently in storage, pending the opening of a suitable repository. It concerns the following categories: HLW, ILW-LL, LLW-LL, tritiated LILW-SL.

This waste breaks down as follows:

- 2,293 m^3 HLW;
- 41,757 m^3 ILW-LL;
- 82,536 m^3 LLW-LL;
- 2,905 m^3 tritiated LILW-SL.

Appendix 3 describes the specific management solutions studied further to the Act of 28 June 2006 for HLW, ILW-LL and LLW-LL. The storage solutions for tritiated waste, designed to allow time for radioactive decay before disposal, are described in Box 3.2 (taken from the CEA's guideline document on tritiated waste storage, submitted to the Minister of Ecology, Energy, Sustainable Development and Territorial Planning at the end of 2008, in accordance with the Act of 28 June 2006, see Chapter 1).

Box 3.2:

Excerpt from the "Guideline document on tritiated waste storage"

As a result of its research and development activities - particularly those with a view to National Defence applications - the CEA produces waste containing tritium, for which no final disposal solution has yet been found. This waste is currently stored at the Valduc and Marcoule sites after being treated and conditioned. Furthermore, industrial companies and medical and pharmaceutical research laboratories use tritium - or have done so in the past - for a number of applications which have led to the production of tritiated waste, a small amount of which is still awaiting a disposal solution. Lastly, the ITER facility[19] will also generate tritiated waste as of 2020.

Andra's existing surface disposal sites are not designed to accommodate this type of waste. .../...

The proposed solution is for producers to treat and condition this waste and then to store it at decay storage facilities to be built close to the main production sites (Valduc, Marcoule, Cadarache, etc.).

In view of the characteristics and mobility of tritium, efforts must be made to ensure that the environmental impact of these storage facilities is as low as reasonably achievable. To this end, the waste that releases the most gas, whether it is pure tritiated or irradiant tritiated waste, will have to be either detritiated, or conditioned in gastight containers before going to the storage facility. This is particularly the case of waste from the Valduc site and ITER.

3.1.2 Forecasts for the period 2008-2030

As mentioned in the introduction to this chapter, evaluations only concern waste from the operation or dismantling of existing or "committed" facilities[20] as at the end of 2007.

In order to estimate future waste production, assumptions must be made and scenarios defined concerning the activities behind it (see Section 2.3.3). These assumptions and scenarios make allowance for any changes contemplated by industry. The scenarios for each activity sector are described in detail in the various subchapters of Chapter 4.

These scenarios assume that existing industrial activities will go on as they are. The assumption has thus been made that nuclear power production will continue, and that all fuel will be processed, apart from certain types of civil fuel (EL4 fuel from the Brennilis heavy-water prototype reactor and from the Osiris research reactor, various experimental fuels and that used in the first-generation of gas-cooled reactors that has yet to be processed).

Forecasts for the end of 2020 and 2030 given in this edition of the National Inventory are based on the following assumptions with regard to the composition, operation and cleanup/dismantling of nuclear power plants and fuel processing facilities:

In order to estimate future waste production, assumptions must be made and scenarios defined concerning the activities behind it.

19 Waste produced by the ITER facility is not accounted for in the 2009 National Inventory because it had not been licensed for construction by the end of 2007 (construction licensing decree not signed as at the end of 2007). Nevertheless, the facility and an estimate of the waste it is expected to produce are described in a box in subchapter 4.5.

20 Construction licensing decree signed.

- 59 "committed" nuclear power reactors: the 58 existing PWRs and, as of 2013, one EPR (the Flamanville EPR);
- all these reactors will remain in service for the same length of time, that is to say 40 years;
- nuclear power generation will stand at 430 TWh net/year, plus 13 TWh/year as of 2013, when the Flamanville EPR is scheduled to be commissioned;
- reactors will be refuelled at a rate of 1,100 tHM/year[21] (about 1,000 tHM of UOX and 100 tHM of MOX divided among the 22 licensed reactors as at the end of 2007) plus 70 tHM/year of enriched, recycled uranium (for refuelling the four reactors using this type of fuel as of 2010);
- forecast management modes (high burnup) will be implemented;
- dismantling work on the six natural-uranium, gas-cooled reactors (Bugey 1, Chinon A1, A2, A3, Saint-Laurent A1, A2), the Brennilis heavy-water reactor, the Chooz A PWR and the Creys-Malville (Superphénix) fast breeder reactor will be more than 80% completed by the end of 2030 (the end of the dismantling programme is scheduled for 2035);
- spent fuel will be processed at the La Hague plant at a rate of 850 tHM of UOX/year until 2030 (see note below). The processing of MOX fuel mixed with UOX and enriched, recycled uranium will be taken into consideration as of 2031;
- decommissioned fuel processing plants - UP1 in Marcoule and UP2-400 in La Hague - will have been cleaned up and dismantled by the end of 2030.

Dismantling work on PWRs currently in operation will not begin before 2030, in other words, about ten years after the first have been shut down, bearing in mind the 40-year lifetime assumed for this type of reactor. Similarly, AREVA assumes that dismantling work on the La Hague UP2-800 and UP3 fuel processing plants will begin after 2030.

Dismantling work on some of the existing CEA civil research facilities and some CEA/DAM (Military Application Division) facilities will be in progress at the end of 2030.

Appendix 2 gives an assessment of all "committed" waste, based on the assumption that nuclear power reactors remain in use, together with the additional assumptions required.

Note:

Owing to the time required to compile data, there is a time lag in the National Inventory (as in most statistical reports) between the data "cut-off" date (31 December 2007) and the date of publication (June 2009). The scope of this scenario and some of the assumptions mentioned above have, of course, seen some changes since the end of 2007. These changes will be taken into account in future updates of the National Inventory.

Thus, when the time comes (and subject to licensing requirements), the construction of a second EPR (Penly), announced by the French President at the beginning of 2009, means that another nuclear power reactor must be added to the 59 accounted for in this Inventory.

21 tHM: tonnes of heavy metal

In addition, EDF intends to recycle more of the radioactive materials resulting from fuel (uranium and plutonium) processing in PWRs (see Subchapter 4.2). Along with this increased recycling, the following phenomena will be observed:

- a slower, more moderate change in burnup, the aim being to ensure that the radioactive material retains a sufficiently high energy potential after processing; consequently, the possible future management options mentioned here have yet to be confirmed by EDF;
- the rate at which spent fuel is processed at the La Hague plant will increase from 850 tonnes/year to around 1,000 tonnes/year; this increase will have no impact on total quantities of waste, but it will step up the rate at which fuel processing waste is conditioned.

3.1.2.1 Forecast stocks for 2020 and 2030, with all activity sectors taken into account

Table 3.5: Forecast waste stocks (in m^3 conditioned equivalent)

	Volumes as at the end of 2007 at disposal or storage facilities	Volumes as at the end of 2020 at disposal or storage facilities	Volumes as at the end of 2030 at disposal or storage facilities
HLW	2,293 of which 74 is spent fuel	3,679 of which 74 is spent fuel	5,060 of which 74 is spent fuel
ILW-LL	41,757	46,979	51,009
LLW-LL	82,536	114,592	151,876
LILW-SL	792,695	1,009,675	1,174,193
VLLW	231,688	629,217	869,311
TOTAL	**1,150,969**	**1,804,142**	**2,251,449**

Table 3.5 calls for the following comments:

- **HLW**
  The quantity of high-level waste over this period is estimated by taking into account a flow that depends, in particular, on the burnup of spent fuel delivered by EDF, which will see a gradual increase over the period, and an improvement in the permissible incorporation rate of fission products in vitrified waste packages (see Subchapter 4.3).

- **ILW-LL**
  Stocks as at the end of 2020 have dropped by 8% compared with those shown in the 2006 National Inventory. The reasons given in Subsection 3.1.1.1 to account for the fall in ILW-LL stocks at the end of 2007 offer a partial explanation for the decrease forecast for the end of 2020. The chief factor in the drop in the forecast volume of this category of waste between 2008 and 2020 is the revised production ratio for packages of compacted hulls and end caps (1 CSD-C per tonne of processed fuel in the 2006 National Inventory compared with 0.85 CSD-C per tonne in this Inventory).

The period 2008-2030[22] will see recovery and conditioning work carried out on legacy waste, the volumes of which are already accounted for in stocks as at the end of 2007.

- **LLW-LL**
  The increase in volume over the period 2008-2030 is due to the dismantling of gas-cooled reactors from 2008 onwards (reminder: the graphite structures currently in these reactors are not considered as waste as at the end of the 2007). Dismantling work on the old G1 gas-cooled reactor on the Marcoule site is supposed to start around 2030.

  Radium-bearing waste produced over this period will mostly come from cleanup operations on legacy sites and non-nuclear industrial sites (see Subchapter 4.9), in particular those of (i) CEZUS, where radium-bearing waste is generated as a result of zirconium sponge manufacturing activities and (ii) RHODIA, where residues will be generated by processes for recovering crude thorium hydroxides and suspended particulate matter (SPM), which are by-products of rare earth mineral processing.

- **LILW-SL**
  The more than 30% drop in forecast waste production compared with the values given in the 2006 National Inventory can be largely explained by improved waste sorting at production sites and by the fact that some of this waste is now included in the VLLW management solution. It should nonetheless be observed that a significant amount of dismantling waste in this category will be produced over the period 2008-2030.

- **VLLW**
  The significant increase in this category of waste is due to the dismantling programmes scheduled over the coming years. Although equipment dismantling and building demolition activities only generate very-low-level waste, the quantities involved are significant.

22 Article 7 of the Act of 28 June 2006 stipulates that the owners of intermediate-level, long-lived waste produced before 2015 should condition it by 2030 at the latest.

Note that 37,000 m^3 of concrete blocks are to be produced for conditioning sodium from Superphénix. These packages should be made by 2010 and stored on site for thirty years, after which they will be managed as very-low-level waste. Alternative disposal solutions could be contemplated for this waste, which is nevertheless included in this management solution for the period 2008-2020 in this National Inventory. The figures in the table also take into account 120,000 tonnes (around 110,000 m^3) of metal waste due to the dismantling of EURODIF's Georges Besse I gaseous-diffusion enrichment plant between 2015 and 2023. This metal waste could be recycled for use in the nuclear industry[23], in which case it would no longer be considered as VLLW.

In view of the two points above, the volumes of VLLW announced for 2020 and 2030 may present a problem with regard to the current capacity of the VLLW disposal facility (see Section 1.4.5).

The volumes of VLLW forecast for the end of 2020 and 2030 regarding the current capacity of the CSTFA facility should be considered with reservations.

3.1.2.2 Waste stocks as at the end of 2020 and 2030 compared with storage capacities

As mentioned in Chapter 2, waste producers submit declarations for this National Inventory and future editions, providing data on waste storage for categories where a final management solution is still being studied. The management solutions concerned are defined in the Ministerial Order of 9 October 2008. The storage facilities to be declared are those receiving waste in the HLW, ILW-LL, radium-bearing and tritiated waste categories. Graphite waste is not concerned as the stacks and reflectors of old natural-uranium, gas-cooled reactors, which account for most graphite waste, have yet to be dismantled.

Information on these storage facilities and, in particular, their total capacity and used capacity as at the end of 2007 is given in Table 3.6.

Furthermore, Article 11 of Decree 2008-357 of 16 April 2008, referred to as the "PNGMDR decree" (see Chapter 2), entrusts Andra with the task of studying and proposing to the Ministers concerned with energy any "possible changes in the storage of high-level and intermediate-level, long-lived waste", after assessing requirements in this area. Appendix 4 presents an initial assessment of these requirements.

23 Talks between AREVA and Andra are in progress on this subject

Table 3.6: Storage facilities for HLW, ILW-LL and radium-bearing and tritiated waste

Management solution	Location	Storage facility operator	Name of storage facility	Commissioning date	Forecast lifetime or closure date
HLW	Manche	AREVA	R7	1989	2040
	Manche	AREVA	T7	1992	2040
	Manche	AREVA	EEV/SE	1996	2040
	Gard	CEA	AVM	1978	2035
	Gard	CEA	APM	1969	50 years[24]
ILW-LL	Manche	AREVA	ECC	2002	2040
	Manche	AREVA	EDS/EDT	1990	2040
	Manche	AREVA	EDS/ADT1	2006	2040
	Manche	AREVA	EDS/ADT2	2008	2040
	Manche	AREVA	EDS/EDC-A	1990	2040
	Manche	AREVA	EDS/EDC-B and EDS/EDC-C	1990	2040
	Manche	AREVA	Building S	1987	2040
	Manche	AREVA	Building ES	1995	2040
	Gard	CEA	EIP	2000	50 years
	Bouches-du-Rhône	CEA	INB 56	1968	39 years[25]
	Bouches-du-Rhône	CEA	CEDRA	2006	50 years
Tritiated waste	Côte d'Or	CEA/DAM	Individual storage facility for solid tritiated waste	1982	50 years
Radium-bearing LLW-LL	Charente-Maritime	RHODIA	Plant site (Chef de Baie)	1988	30 years
	Isère	CEZUS	Building 480	2005	-
	Vaucluse	SOCATRI	North 1 (12 Q) and North 2 (13 Q)	2006	12 years
	Bouches-du-Rhône	CEA	ICPE 420 and 465	1995	20 years

24 Forecast lifetime at the time the storage facility is commissioned. Any extension of this lifetime is subject to ASN authorisation.

25 No more new waste packages have been received at this storage facility since 2007.

26 Radium-bearing lead sulphate packages, 500-litre concrete pacakges containing filtration sludge, 870 litres with 700-litre drums of concentrates, 870 litres of slightly irradiating waste, 500-litre drums of "medium" irradiating waste, 1,800- or 1,000-litre concrete packages, source blocks, radium, radium-tipped lightning rods.

27 500-litre concrete packages containing filtration sludge, 870 litres with 700-litre drums of concentrates, 870 litres of slightly irradiating waste, 500-litre drums of "medium" irradiating waste, 1,800- or 1,000-litre concrete packages, source blocks,radium-tipped lightning rods.

28 The radium-bearing waste (7,226 m^3) produced by Rhodia is not the only type of waste found at this storage facility. 4,500 m^3 of thorium nitrate and 14,000 m^3 of crude thorium hydroxide is also stored there.

Waste packages for which the storage facility was designed	Waste packages stored as at the end of 2007	Total waste storage capacity (m^3)	Used capacity as at the end of 2007 (m^3)	Effective or forecast commissioning date of extension where appropriate	Extension capacity (m^3)
CSD-V CSD-B	CSD-V CSD-B	788	684	NA	NA
CSD-V	CSD-V	630	454	NA	NA
CSD-V	CSD-V	756	445	2,012	737
AVM vitrified waste packages AVM operating waste packages	AVM vitrified waste packages AVM operating waste packages	665	579	NA	NA
PIVER glass	PIVER glass	46	13	NA	NA
CSD-C	CSD-C	3,806	1,114	2,022	3,806
CBF-C'2 CAC	CBF-C'2 CAC	7,684	5,111	NA	NA
LILW-SL packages	CBF-C'2 (temporary storage)	779	219	NA	NA
CBF-C'2		3,186	0	NA	NA
Packages of cemented hulls and end caps		977	0	NA	NA
Packages of cemented hulls and end caps	Packages of cemented hulls and end caps	2,484	2,277	NA	NA
Bituminised sludge packages	Bituminised sludge packages	4,760	2,597	NA	NA
Bituminised sludge packages		6,426	0	NA	NA
EIP drums	EIP drums	4,235	2,276	2,012	4,235
Misc. packages[26]	Misc. packages[25]	7,500	7,425	NA	NA
Misc. packages[27]	500 l packages MI waste, 870l FI waste, 500 l concrete shells of filtration sludge	6,000	618	2,014	6,350
Tritiated waste	Tritiated waste	3,100	2,368	2,012	3,000
Radium-bearing waste (RRA and RSB)	Radium-bearing waste (RRA and RSB)	56,980	25,726[28]	NA	NA
Drums of radium-bearing residue	Drums of radium-bearing residue	3,538	1,929	NA	NA
	Lightning rods and cleanup waste	2,600	384	NA	NA
Drums of radium-bearing residue	Drums of radium-bearing residue	5,950	5,950	NA	NA

3.1.2.3 Waste stocks by economic sector as at the end of 2030

The distribution of radioactive waste by economic sector (see Subchapter 1.3) estimated by Andra is shown for each management solution as at the end of 2030 in Figures 3.20 to 3.24.

It can be seen that the nuclear power economic sector represents a growing share of waste in all categories, especially HLW, LLW-LL and VLLW. Dismantling operations (on first-generation GCRs, the Superphénix reactor, front-end cycle facilities) are the main reason for the significant increase in LLW-LL and VLLW.

Figure 3.20: Distribution of HLW by volume and by economic sector as at the end of 2030

Nuclear power	**90.6%**
Defence	**4.8%**
Research	**4.6%**

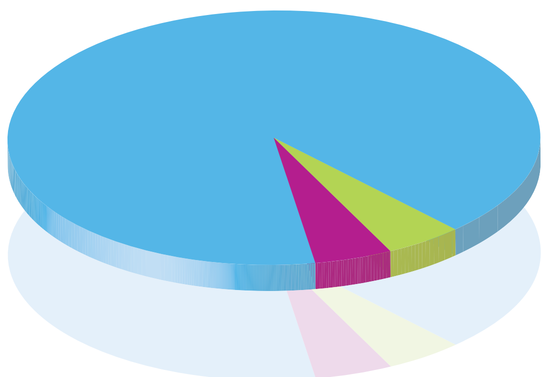


Figure 3.21: Distribution of ILW-LL by volume and by economic sector as at the end of 2030

Nuclear power	**64.5%**
Research	**25.9%**
Defence	**9.3%**
Industry apart from nuclear power	**0.3%**

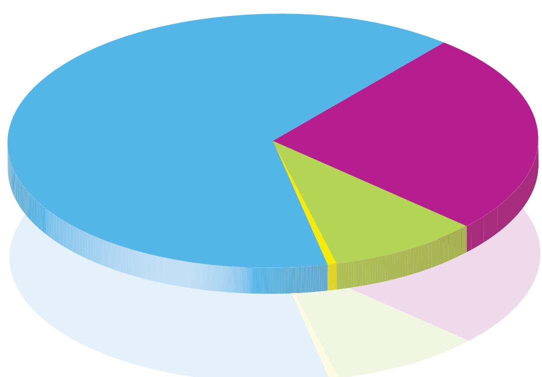


Figure 3.22: Distribution of LLW-LL by volume and by economic sector as at the end of 2030

Nuclear power	**50.3%**
Industry apart from nuclear power	**23.9%**
Defence	**14.3%**
Research	**11.5%**
Medical	**0.01%**

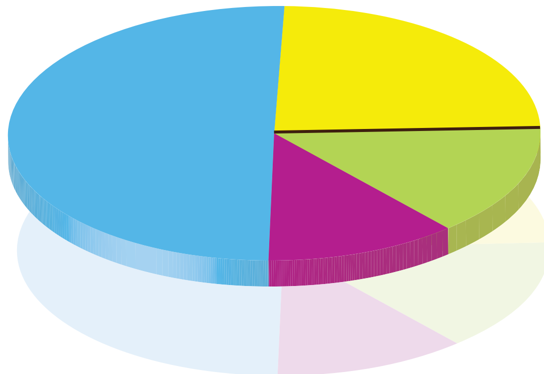


Figure 3.23: Distribution of LILW-SL by volume and by economic sector as at the end of 2030

Nuclear power	**71.1%**
Research	**16.1%**
Defence	**10.3%**
Industry apart from nuclear power	**1.6%**
Medical	**0.9%**

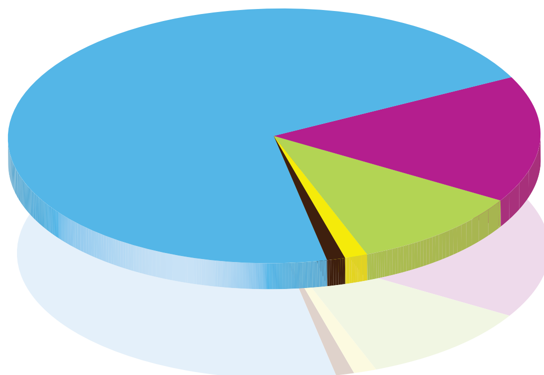
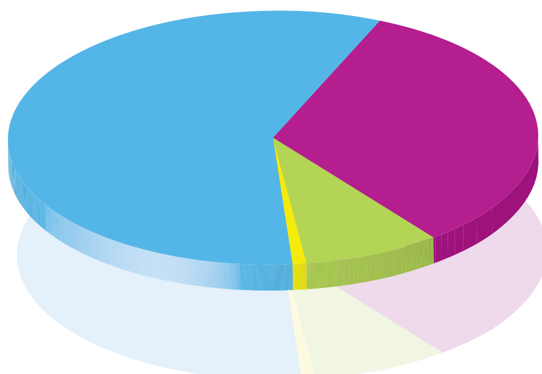


Figure 3.24: Distribution of VLLW by volume and by economic sector as at the end of 2030

Nuclear power	**57.9%**
Research	**33.2%**
Defence	**8.2%**
Industry apart from nuclear power	**0.7%**



3.1.2.4 Radiological content

Table 3.7 gives an estimate of the total radioactivity of waste for 2030. These estimates include a simplified calculation of the radioactive decay of the waste existing in 2007 and the new waste generated over the period.

Table 3.7: Estimated radioactivity as at the end of 2030 (values expressed in TBq, i.e. 10^{12} Bq)

	Alpha	Short-lived Beta-Gamma	Long-lived Beta-Gamma
HLW	32,000,000	193,000,000	614,000
ILW-LL	42,200	2,600,000	1,110,000
LLW-LL	364	6,890	9,890
LILW-SL	1,090	12,840	10,100
VLLW	4.9	3.7	0.7

3.1.2.5 Dismantling and waste conditioning over the period 2008-2030

The period 2008-2030 will be marked by two major changes in the waste management field: a) a rise in the number of dismantling operations and b) the recovery and conditioning of legacy waste.

Dismantling

The nuclear industry is relatively young, dating back to the 1960s, so the main cleanup and dismantling work on nuclear fuel cycle facilities is yet to come and will take place mostly after 2020.

The main cleanup and dismantling work on nuclear fuel cycle facilities is yet to come and will take place mostly after 2020.

This activity generates two types of waste - nuclear and conventional. 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 radioactive nuclear waste zones is all considered radioactive on principle, even if no radioactivity has been detected in it. It is classified by type and by radiological activity (type of radionuclides, lifetime, activity level).

The radioactive waste generated by dismantling operations consists mostly of:

- materials from demolition work (concrete, rubble, scrap metal, glove box walls, piping, etc.);
- decontaminated process equipment (metal parts);
- tools and protective clothing (gloves, vinyl overalls, etc.);
- equipment rinsing effluents.

For technical and economic reasons, preparing and managing dismantling projects calls for an extremely precise estimation of the quantity and type of waste that will be generated, as well as the treatment and conditioning methods to be employed.

An exact inventory of the facilities to be cleaned up must therefore be made first, including all the equipment they contain and their residual contamination level. A thorough knowledge of the facility's past activities is essential for this task.

Operators evaluate the quantities of waste produced based on feedback from past dismantling operations. This feedback is gradually built up in databases which are used to define "technical ratios". The ratios are used to calculate the quantity of waste resulting from the dismantling of each part of a facility, according to the nature and technical characteristics of that part and the radiological contamination measurements taken there. The evaluations take into account all the waste resulting from the operation, including, for example, the volumes of effluent generated by decontamination. Depending on the characteristics of the waste, specific management scenarios are used to assess the quantities of conditioned waste and appropriate long-term management solutions. These scenarios are based on knowledge of treatment and conditioning facilities. They may vary from one producer to another, as each producer has its own strategy for dismantling its facilities.

Most nuclear waste resulting from the dismantling of fuel cycle facilities is in the VLLW category and, to a lesser degree, the LILW-SL category. In some special cases and certain types of facility, it may also belong to the ILW-LL category. Dismantling operations on first-generation, gas-cooled reactors generate low-level, long-lived waste.

Recovery and conditioning of legacy waste

As already mentioned, Article 7 of the Act of 28 June 2006 obliges the owners of intermediate-level, long-lived waste produced before 2015 to condition it by 2030 at the latest.

Table 3.8 shows the proportion of conditioned waste (see Subchapter 2.3 for details on the notion of conditioned waste) as at the end of 2020 and 2030 for each management solution.

The 5% of ILW-LL not conditioned at the end of 2030 can be explained by a small proportion of activated waste generated between 2008 and 2030 by PWR operation and dismantling work. It also includes some (around 1,500 m^3) of the drums of bituminised legacy ILW-LL stored in bunkers at the Marcoule STEL facility. Although there are plans to recondition these drums, they will not have been recovered by 2030.

Note:

As pointed out in Subsection 3.1.1.4, preconditioning and conditioning represent two different stages in the conditioning process for the National Inventory. The Act of 28 June 2006 does not make this distinction. From the legal point of view, the bituminised legacy ILW-LL stored in the bunkers at the STEL facility in Marcoule is conditioned.

Article 7 of the Act of 28 June 2006 obliges the owners of intermediate-level, long-lived waste produced before 2015 to condition it by 2030 at the latest.

Table 3.8: Change in proportion of conditioned waste

	Conditioned waste as at the end of 2007	Conditioned waste as at the end of 2020	Conditioned waste as at the end of 2030
HLW	89%	98%	100%
ILW-LL	49%	75%	95%
LLW-LL	10%	46%	88%
LILW-SL	94%	97%	97%
TOTAL	**85%**	**91%**	**96%**

In Figures 3.25 to 3.30, the same bar graph is used for all waste categories to show progress in the conditioning of waste existing in 2007 and the production of new waste over the period 2008-2030, based on producers' assumptions. The figures given by producers in their waste production forecasts make no distinction between waste from facility operation[31] and that due to dismantling work. Andra has nevertheless estimated the proportion of each of these types of waste for this National Inventory, drawing on available data.

The bar graphs compare:

- the quantity of waste existing in 2007 that had already been conditioned by 2007 and the quantity that will be conditioned by the end of 2030;
- stocks of existing unconditioned or preconditioned waste in 2007. This chiefly concerns legacy waste stored at La Hague, Marcoule and Cadarache. The blue bars illustrate progress in the conditioning of waste existing in 2007 between 2008 and 2030;
- the stock of operating waste produced between 2008 and 2030 that has been conditioned;
- the stock of operating waste produced between 2008 and 2030 that has not been conditioned;
- waste generated by cleanup and dismantling operations performed on reactors, plants and other facilities over the period 2008-2030.

The bar graph specific to graphite LLW-LL highlights the large quantity of waste still to be expected from dismantling operations.

No distinction is made between the conditioned and unconditioned proportions of very-low-level waste as in some cases this type of waste may be disposed of without specific conditioning.

31 Operating waste includes: waste that comes directly from spent fuel conditioned at processing plants (vitrified fission products, cladding waste), waste relating to facility maintenance and the treatment of effluent from the operation of these facilities.

Figure 3.25: HLW (in m^3 conditioned equivalent)

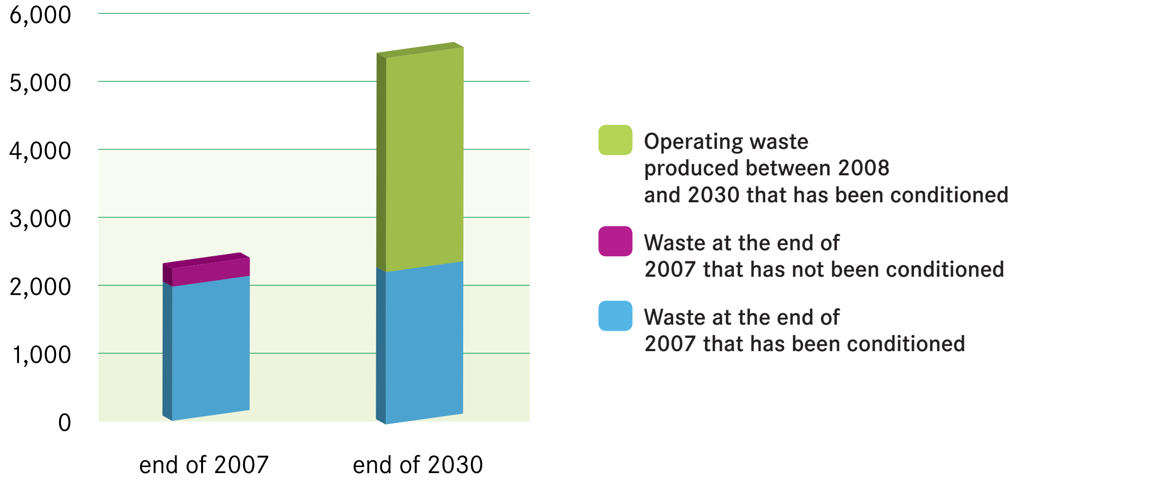


Figure 3.26: ILW-LL (in m^3 conditioned equivalent)

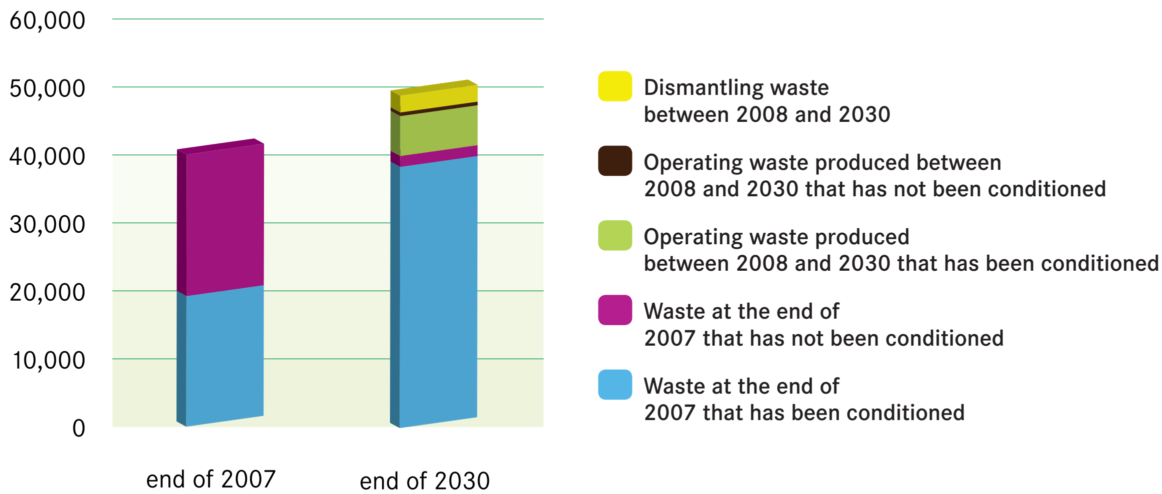


Figure 3.27: LLW-LL (in m^3 conditioned equivalent)

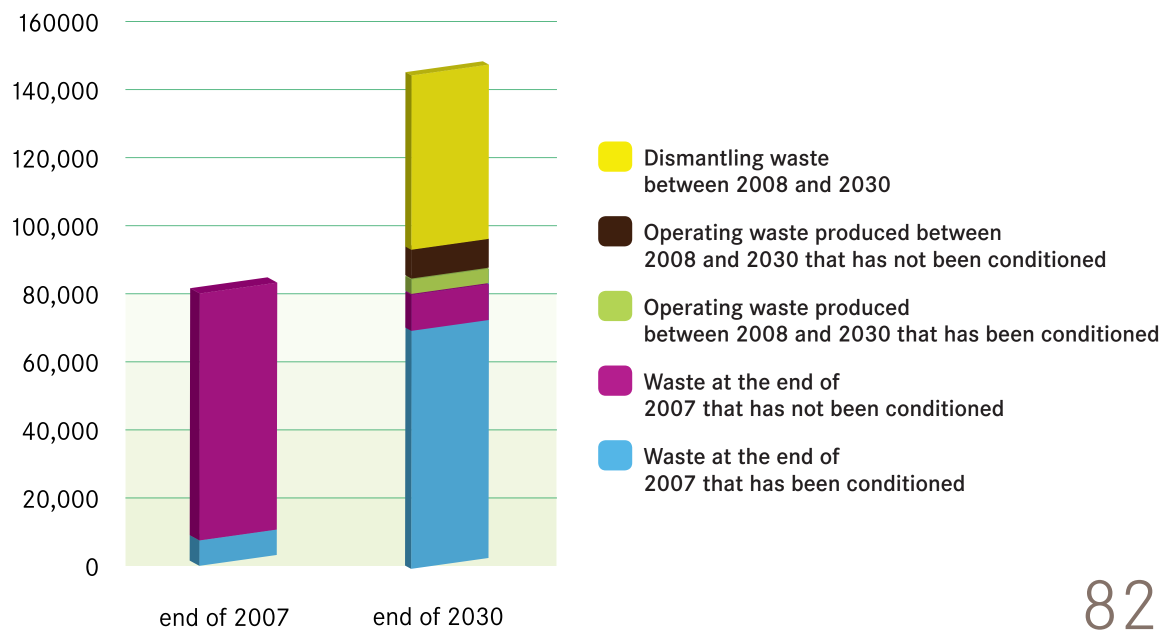


Figure 3.28: Graphite LLW-LL (in m³ conditioned equivalent)

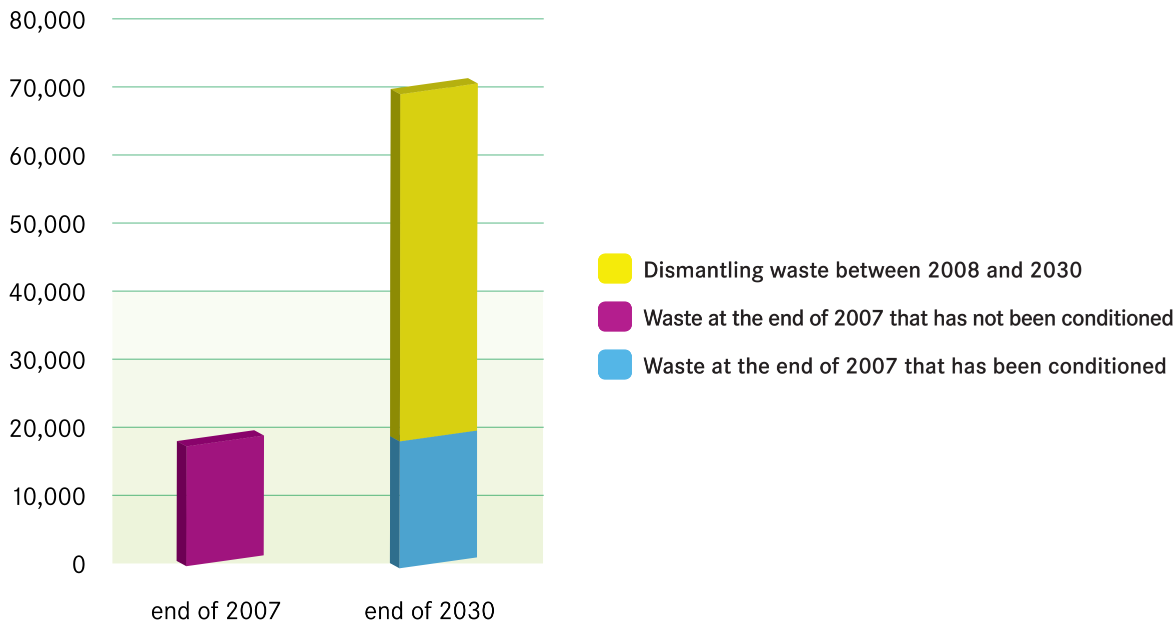


Figure 3.29: LILW-SL (in m³ conditioned equivalent)

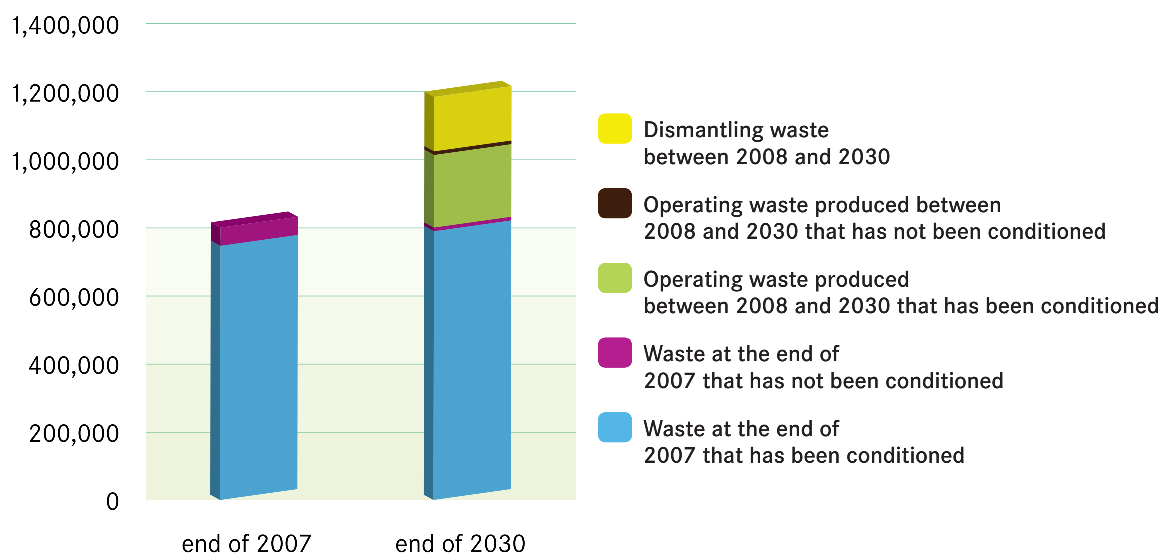
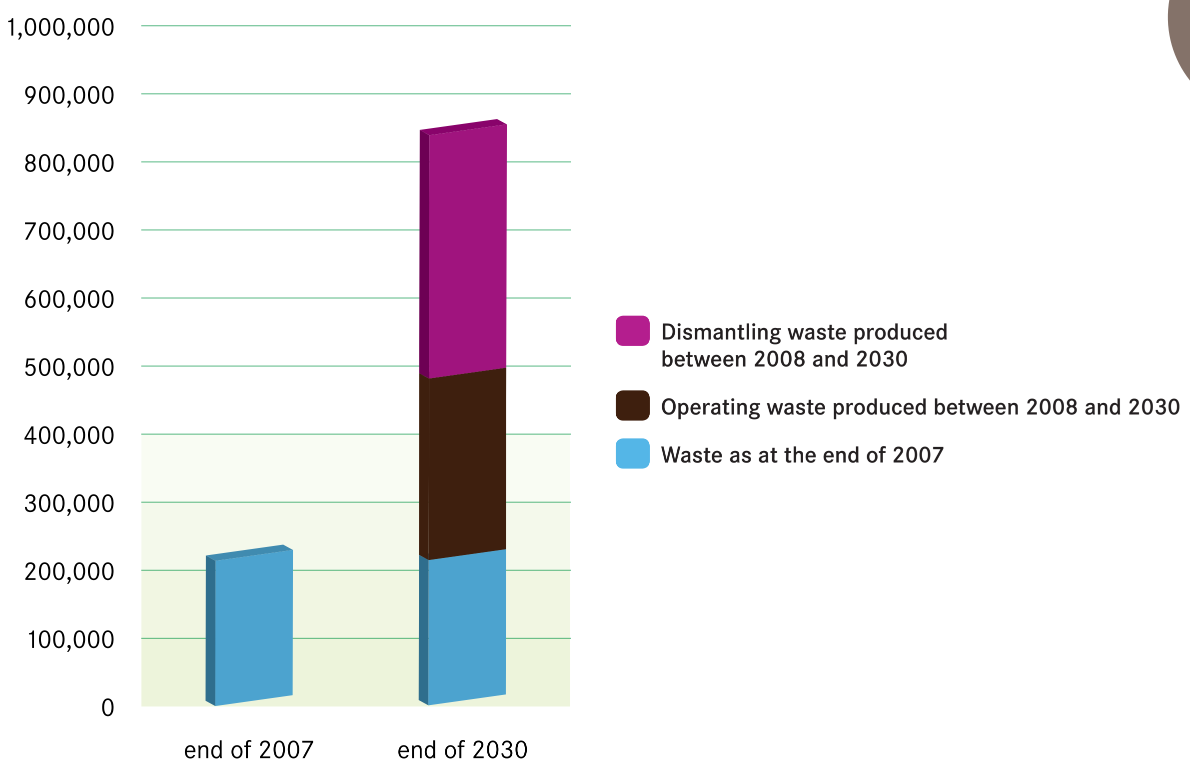


Figure 3.30: VLLW (in m^3)



3.1.3 Outlook beyond 2030

3.1.3.1 Waste from nuclear facility dismantling after 2030

Table 3.9 shows dismantling waste produced beyond 2030 for each management solution. On more than one account, the volumes given are only indicators:

- firstly, with a dateline so far ahead, it is likely that both dismantling techniques and regulations will have changed in the light of feedback from completed dismantling operations. Both techniques and regulations may lead to changes in the nature and volume of waste produced;
- secondly, the table only includes waste from facilities for which the owners have provided data. Note, however, that in the case of basic nuclear installations, this data has been evaluated by operators in accordance with Article 20 of the Act of 28 June 2006.

Details of the facilities included can be found in the various subchapters of Chapter 4 according to activity sector.

Table 3.9: Dismantling waste beyond 2030 (in m^3 conditioned equivalent)

	Front and sup of fuel cycle facilities (fuel processing)[32]	Existing nuclear power plants	CEA civil facilities	CEA/DAM facilities
ILW-LL	3,000	6,000	750	0
LLW-LL	0	0	5,700	6,000
LILW-SL	28,200	249,000	32,000	6,000
VLLW	34,500	468,000	115,000	20,000

3.1.3.2 "Committed" waste

The National Inventory does not set out to give guidelines on energy policy. That responsibility lies with the public authorities. Nonetheless, the decision was made that this National Inventory - like the 2006 edition - should estimate the potential volumes of waste produced by all existing facilities up to the end of their life according to two basic scenarios. This waste is referred to as "committed" waste. The estimates made in this respect should only be seen as indicators, as the assumptions on which they are based may change from one National Inventory to the next.

The detailed estimates can be found in Appendix 2.

The two scenarios considered for the purpose of these estimates are as follows:

- scenario 1: nuclear power production will continue and all fuel will be processed, apart from certain types of civil fuel (EL4 fuel from the Brennilis heavy-water prototype reactor and from the Osiris research reactor, various experimental fuels and that used in the first-generation of gas-cooled reactors that has yet to be processed). This is the scenario on which the National Inventory bases its forecasts of waste volumes as at the end of 2020 and 2030 (see Subchapter 3.2);
- scenario 2: nuclear power production will be discontinued, leading to the end of fuel processing operations and to the direct disposal of the remaining spent fuel. This scenario only serves an illustrative purpose and does not reflect any industrial reality at present.

The decision was made that this National Inventory - like the 2006 edition - should estimate the potential volumes of waste produced by all existing facilities up to the end of their life according to two basic scenarios.

32 UP1 plant dismanlting waste is not accounted for in these figures, but is integrated in the figures relating to CEA civil activities installations

The two scenarios are based on common assumptions:

- Those already mentioned in Subchapter 3.2 for estimating waste as at the end of 2020 and 2030:
  - 59 "committed" nuclear power reactors: the 58 existing PWRs and, as of 2013, one EPR (the Flamanville EPR);
  - all these reactors will remain in service for the same length of time, that is to say, 40 years;
  - nuclear power generation from PWR plants will stand at slightly more than 17,000 TWh, i.e. an average of 430 TWh net/year, plus 13 TWh/year as of 2013, when the Flamanville EPR is scheduled to be commissioned;
  - forecast management modes (high burnup) will be implemented;
  - reactors will be refuelled at a rate of 1,100 tHM/year[33] (about 1,000 tHM of UOX and 100 tHM of MOX divided among the 22 licensed reactors as at the end of 2007), plus 70 tHM/year of enriched, recycled uranium (for refuelling the four reactors using this type of fuel as of 2010);

- An additional assumption required for estimating the total quantity of committed waste: all unloaded PWR fuel (including fuel from the management reserves and last cores, some of which could be reused in later reactors) is taken into account, i.e. a total of around 51,000 tHM, broken down as follows: 50,300 tHM (45,850 tHM of UOX, 1,550 tHM of enriched uranium and 2,900 tHM of MOX) corresponding to fuel from existing PWR plants and the Flamanville EPR until 2040, 420 tHM of EPR fuel from 2041 to 2052 and 180 tHM of fast breeder reactor (Superphénix) fuel.

Scenario 1: nuclear power production continues

Although continued use of nuclear power implies renewing nuclear power plants, the waste produced by future plants (new reactors and, eventually, "generation IV" reactors) is not taken into account here because it is not yet "committed".
UOX fuel will be processed at a rate of 850 tHM/year until 2030 (as indicated in Subchapter 3.2). By the end of 2030, this rate will have risen to 1,250 tHM/year, as the processing of MOX fuels mixed with UOX and enriched, recycled uranium will have started. Processing will continue at this rate until 2043, then residual Flamanville EPR fuel will be mixed and processed with Superphénix fuel until 2055, that is to say, about 3 years after the Flamanville EPR is shut down.

Volumes shown in this context relate to all the activity sectors from which the waste originates and take into account:

- waste stocks existing in 2030;
- operating waste produced beyond 2030;
- dismantling waste beyond 2030 (Table 3.9).

Appendix 2 gives details of how the waste produced according to this scenario has been estimated. Table 3.10 gives an overview of the waste produced for each management solution.

33 tHM: tonnes of heavy metal

Table 3.10: Scenario 1 (nuclear power production continues): present and future volumes of waste production (including dismantling) in m^3 conditioned equivalent

HLW	7,910 of which 74 is spent fuel
ILW-LL	65,300
LLW-LL	164,700
LILW-SL	1,530,200
VLLW	1,560,200

Note:

The volumes shown above have been rounded off to the nearest ten m^3 for HLW, and to the nearest hundred m^3 for ILW-LL, LLW-LL, LILW-SL and VLLW.

In view of the uncertainties - which can be significant - concerning these estimations, additional safety margins may be required in studies on waste disposal solutions in order to define dimensioning inventory models.

Box 3.4 shows existing or planned disposal capacities for the different management solutions, as well as used capacities as at the end of 2007 at facilities operated by Andra.

Box 3.4:

Existing or planned disposal capacities

Subchapter 1.4 gives the disposal capacities of facilities operated by Andra: the CSM waste disposal facility in north-western (Manche), which is "full", and the LILW (CSFMA) and VLLW (CSTFA) disposal facilities in north-eastern France (Aube). Disposal capacities have also been evaluated in connection with disposal projects developed by Andra for the HLW, ILW-LL and LLW-LL management solutions (see Appendix 3). These capacities are based on "envelope" inventories produced by Andra. Inventory models, which are preliminary models in the case of LLW-LL and dimensioning models in the case of HLW and ILW-LL, do include safety margins, particularly for volume capacity.

The following table shows the volume capacities of existing and future repositories operated by Andra.

Management solution	Existing or planned capacity (in m^3)	Used capacity as at the end of 2007 (in m^3)
HLW	6,330*	0**
ILW-LL	81,105*	0**
LLW-LL (graphite)	100,000 (or 23,000 t)	0**
LLW-LL (radium-bearing)	70,000 (or 60,000 t)	0**
LILW-SL	1,527,000 (CSM + CSFMA)	735,053
VLLW	650,000	89,336

*These capacities were estimated for feasibility studies for a deep repository in 2005, based on 45,000 tHM of spent fuel to be processed and the scenario assuming that nuclear power production will continue. They are now being reviewed as part of deep repository design studies, making allowance for a higher tonnage of spent fuel to be processed (the increased tonnage of unloaded fuel is explained by the broader energy scope considered and the conservative assumption made for partially irradiated fuel processing (last cores, management reserves). This fuel tonnage is comparable to that given in this edition of the National Inventory.

**Planned disposal facility.

Scenario 2: Nuclear power production discontinued

The predicted lifetime of 40 years assumed for all reactors means that the first reactors compatible for use in recycling plutonium as MOX fuel will be shut down around 2020 and the last of them around 2030.

The amount of plutonium required to fuel today's 22 MOXable reactor units until the end of their life is calculated on the basis of their decommissioning schedule. After deducting plutonium stocks existing at the end of 2007, and allowing for the quantities expected from future processing, based on a rate of 850 tonnes of UOX fuel per year, processing operations should be brought to a definitive halt in 2019, according to an EDF calculation. This date should ensure that the stock of separated plutonium (i.e. excluding the plutonium contained in spent fuel) has been completely eliminated by the time the last MOXed reactor shuts down in 2030. The 2006 National Inventory gave a slightly different date (2017) for the same scenario. As EDF only contemplates processing fuel from the Superphénix fast breeder reactor for use in future nuclear power plants, this scenario considers that this fuel is not processed. The resulting plutonium deficit means that the date for stopping processing operations is shifted to 2019.

The end of processing operations in 2019 implies that: a) any spent fuel that has not been processed by that date (nearly 28,000 tonnes) is to be considered as waste and b) the only waste to be taken into account as from that date is dismantling waste for processing facilities. However, fuel-cycle front-end facilities and EDF reactors still in operation will go on producing waste.

Appendix 2 gives details of the estimates made according to this scenario.

Table 3.11 gives an overview of the waste produced for each management solution.

Table 3.11: Scenario 2 (nuclear power production is discontinued): present and future volumes of waste production (including dismantling) in m^3 conditioned equivalent

HLW (spent fuel) **HLW (vitrified waste)**	89,000 (28,000 tonnes) 3,500
ILW-LL	58,900
LLW-LL	164,700
LILW-SL	1,466,500
VLLW	1,500,300

Note 1:

The volumes shown above have been rounded off to the nearest ten m^3 for vitrified HLW, to the nearest hundred m^3 for ILW-LL, LLW-LL, LILW-SL, and VLLW, and to the nearest thousand m^3 for spent fuel.

Note 2:

As a reminder, waste volumes given in the National Inventory are expressed in conditioned equivalent terms, i.e. the volume occupied by the waste before delivery to the long-term manager (Andra in most cases). Any supplementary volumes that might be added at the time of disposal are ignored (for example, it is assumed that intermediate-level, long-lived waste will be grouped together in concrete packages for deep disposal). The 28,000 tonnes of spent fuel for which no use has been found in this scenario represents around 11,000 m^3 of "bare" assemblies and some 89,000 m^3 once it has been placed in suitable containers for deep disposal. This is based on the assumption made by Andra in its deep disposal feasibility studies in 2005 that this waste would be conditioned in disposal containers (it is assumed that the thousand Superphénix fast breeder reactor assemblies are conditioned like MOX fuel).

Note 3:

In 2019, when spent fuel processing comes to an end, the stock of depleted uranium should approach the stock forecast for the end of 2020 (see Subchapter 3.2), that is to say, around 332,000 tonnes.

radioactive materials

3.2

These substances have recycling potential. Consequently, neither their holders nor the public authorities consider them as waste. Article L542-1-1 of the French Environmental Code, amended by the Act of 28 June 2006, defines radioactive material as a radioactive substance for which subsequent use is planned or intended, if necessary, after treatment (see Chapter 1).

The following radioactive materials are presented here:
- natural uranium from mining activities;
- enriched uranium;
- recycled uranium (from spent fuel following processing);
- depleted uranium;
- thorium;
- suspended particulate matter (a by-product of rare earth processing);
- fuel in use at nuclear power plants and in research reactors;
- spent fuel awaiting processing;
- plutonium obtained from spent fuel after processing.

A radioactive material is defined as a radioactive substance for which subsequent use is planned or intended, if necessary after treatment.

Some materials, such as plutonium and some of the depleted uranium in MOX fuel, are already used, while others have been stored pending reuse.

The quantities of radioactive materials accounted for at the end of 2007 and the sites[34] where they are stored are shown below.

Natural uranium from mining activities

As at 31 December 2007, some **27,600 tonnes of natural uranium from mining** activities were stored at AREVA's Malvési (Aude) and Tricastin (Drôme) sites and, to a lesser degree, at its La Hague (Manche) and Romans (Drôme) sites and at CEA sites.

Natural uranium is mined (all French mines are now closed and natural uranium is imported), then transformed into enriched uranium to make nuclear fuel.

34 Although the Tricastin site, referred to several times here, is actually located in the Drôme (for the most part) and Vaucluse, it is considered to be located entirely in the Drôme by convention.

For several years now, depleted uranium has been regularly used as a matrix for MOX fuel, which is a mixture of uranium and plutonium made in France at the Melox plant.

Enriched uranium

Enrichment consists in increasing the concentration of uranium-235 (an isotope that only represents a minute proportion of natural uranium) to obtain a material that can be used to make fuel for nuclear light-water reactors.

EURODIF's Georges Besse I plant uses the gaseous-diffusion enrichment process. Gaseous uranium flows through diffusers that separate uranium-235 and uranium-238, by exploiting the difference in the atomic weight of these two isotopes.
This creates two streams, one enriched and one depleted (i.e. with a high and low concentration of U-235 respectively).

As at 31 December 2007, some **3,300 tonnes of enriched uranium** were stored at AREVA's Tricastin (Drôme), La Hague (Manche), Romans (Drôme) and Pierrelatte (Drôme) sites, as well as at CEA sites and EDF sites in the form of new UOX fuel assemblies.

Depleted uranium (DU)

Depleted uranium, which contains only about 0.3% of the uranium-235 isotope, is transformed into a solid, stable, incombustible, insoluble and non-corrosive material, a black powder called uranium oxide (U_3O_8).

As at 31 December 2007, some **254,800 tonnes of DU were stored** in France at the following sites: 149,100 tonnes at AREVA's Tricastin (Drôme) site and around 104,600 tonnes at its Bessines-sur-Gartempe (Haute-Vienne) site, 124 tonnes at CEA sites, while the rest consisted mainly of in-process inventory relating to MOX fuel fabrication and stocks stored at EDF sites as new MOX and fast neutron reactor fuel assemblies.

For several years now, depleted uranium has been regularly used as a matrix for MOX fuel, which is a mixture of uranium and plutonium made at the Melox plant in Marcoule (Gard) in France. This represents about a hundred tonnes per year.

Re-enriching depleted uranium might also prove to be worthwhile economically. The rising cost of natural uranium leads to a demand for enrichment plants to reduce tails assays. This also means exploiting the quantities of depleted uranium produced during periods when uranium prices are low. Today, the cost of natural uranium is high, which makes it worth taking advantage of the difference in U-235 content between the richest depleted uranium inventory and the depleted uranium produced today. With this in mind, AREVA has begun an initial re-enrichment campaign concerning 8,000 tonnes of depleted uranium.

Within the next few years, centrifuge processes will make it economically viable to re-enrich depleted uranium with even lower assays. Within this context, re-enrichment will concern all existing stocks of depleted uranium (or "tails") over the next few decades. The rate at which this is done depends both on the market price of natural uranium and industrial capacity. These operations could be spread over 30 to 50 years, which is the period over which existing stocks have been built up. New stocks of depleted uranium will build up; these will consist of secondary tails (with enrichment to around 0.2%).

At the same time, new technology such as laser enrichment should achieve even more effective separation. A laser enrichment plant using the SILEX process (the name comes from "separation of isotopes by laser excitation") is currently under construction in the USA. It appears that secondary tails resulting from the re-enrichment process mentioned above could eventually be re-enriched again. This would produce tertiary tails with an enrichment target below 0.1%.

This separation into clearly defined phases is, of course, partly theoretical and stocks will contain secondary and tertiary tails at the same time; it will be possible, for example, to re-enrich tails directly using the laser process.

Lastly, stocks of secondary, or even tertiary, tails could also be reused on a large scale in fourth-generation fast neutron reactors, which burn uranium-238. It is already known that the fuel for these reactors will be made up of plutonium and depleted uranium. Some of this material will be obtained by further processing of UOX and MOX fuel currently in storage, and some will be depleted uranium (tails) from enrichment operations.

For the next generation of fast neutron reactors, expected after 2040, spent fuel recycling technology will thus exploit the tails of that period to the full. This means that secondary and tertiary tails will represent considerable fuel reserves.

Recycled uranium (from spent fuel after processing)

The uranium extracted from spent fuel at processing plants (or recycled uranium (URT)) makes up about 95% of the mass of the spent fuel and contains a significant amount of the U-235 isotope. The residual enrichment level is around 0.7% to 0.8% uranium-235 for PWR fuel with a burnup of 45 to 55,000 MWd/t. Re-enrichment is necessary for reuse in light-water reactors such as those currently operated by EDF.

Recyled uranium is stored either as UF_6 or as U_3O_8 depending on the management method adopted (re-enrichment for fuel fabrication purposes or storage).

Most French -owned recycled uranium belongs to EDF, the national electric utility, while the rest belongs to AREVA and the CEA.

As at 31 December 2007 **21,180 tonnes of recycled uranium** were stored (excluding the small amounts of uranyl nitrate in-process inventory that had yet to be converted at that date) at AREVA's Tricastin (Drôme) and La Hague (Manche) sites.

EDF recycles some uranium (currently in two reactors at the Cruas NPP) after re-enrichment to increase the uranium-235 concentration. The amount of uranium recycled largely depends on the market price of natural uranium, the direct competitor of recycled uranium.

As at 31 December 2007, some **2,770 tonnes of foreign recycled uranium** were stored in France. This is owned by AREVA's foreign customers that have adopted a fuel-recycling strategy.

Thorium

Thorium is found as thorium hydroxide or thorium nitrate. As part of its rare earth mineral processing activities, RHODIA ELECTRONICS & CATALYSIS produced:

- crude thorium hydroxide, a compound that comes from processing monazite using the chloride process, between 1970 and 1987;
- thorium nitrate, produced by processing monazite using the nitrate process, until 1994.

As at 31 December 2007, some 7,134 tonnes of thorium were stored as nitrate and hydroxides at the RHODIA ELECTRONICS & CATALYSIS plant in La Rochelle (Charente-Maritime).

A further 2,265 tonnes of thorium, mostly owned by AREVA, were stored at the CEA's Cadarache (Bouches du Rhône) site. In all, **9,399 tonnes of thorium** were stored at the La Rochelle and Cadarache sites as at the end of 2007.

Suspended particulate matter (SPM)

Suspended particulate matter (SPM) is produced by the treatment used to neutralise chemical effluent produced at the RHODIA ELECTRONICS & CATALYSIS plant. This SPM contains, on average, 25% rare earth oxides.

As at 31 December 2007, **21,672 tonnes of SPM**, a by-product of rare earth processing, were stored at the RHODIA ELECTRONICS & CATALYSIS plant in La Rochelle.

Fuels in use and spent fuels

Stocks of fuel in use and spent fuel exist at any given time. As they contain uranium and plutonium, their owners regard them as recoverable radioactive materials. These stocks are generally divided into:

- **uranium oxide fuels**, which account for the greater part. EDF mostly uses fuel made from enriched natural uranium (UOX), as well as a smaller amount of re-enriched, recycled uranium;
- **mixed uranium oxide-plutonium oxide fuel (MOX),** that EDF is licensed to use at some of its power plants;
- **Superphénix** fast breeder reactor fuel, which is no longer in use (the plant has been decommissioned);
- **CEA civil fuel**, used in certain reactors specifically devoted to research activities. There is a greater variety of this fuel in terms of form and physical-chemical composition compared with EDF fuel, but there is far less of it;
- **fuel relating to National Defence activities,** used either in reactors designed for making material for the nuclear deterrent, or in reactors on board submarines.

EDF's strategy gives priority to the processing of enriched natural uranium oxide fuel. Enriched, recycled uranium and MOX fuel will not be processed until around 2030.

Once removed from the reactor core, EDF fuel assemblies are stored in pools, first at the actual power plant, then at the La Hague plant, to allow their radioactivity to decay.

- **fuel in use at nuclear power plants and in research reactors**

As at 31 December 2007, the following quantities of fuel were in use at French NPPs:

- about **4,500 tHM of UOX fuel** in the 19 PWR power plants in France;
- about **79 tHM of enriched, recycled uranium fuel** in the 2 reactors of the Cruas (Ardèche) nuclear power plant;
- about **290 tHM of MOX fuel** in the following NPPs: Le Blayais (Gironde), Chinon B (Indre-et-Loire), Dampierre (Loiret), Gravelines (Nord), Saint-Laurent B (Loir-et-Cher) and Tricastin (Drôme);
- about **5 tHM of fuel (including some 3 tHM of Phénix fast neutron reactor fuel)** in the CEA's experimental reactors.

- **Spent fuel awaiting processing**

The following types and quantities of fuel were awaiting processing at the end of 2007:

- **spent UOX fuel:** about **3,584 tHM** at the 19 PWR power plants in France and about **7,920 tHM (of which 7,910 French-owned)** at the La Hague (Manche) site;
- **spent recycled uranium fuel:** about **31 tHM** at the Cruas nuclear power plant and about **220 tHM** at the La Hague site;
- **spent MOX fuel:** about **308 tHM** at the following NPP sites: Le Blayais, Chinon B, Dampierre, Gravelines, Saint-Laurent B and Tricastin and some **720 tHM (of which 710 French-owned)** at the La Hague site;
- **spent fast neutron reactor fuel: 104 tHM** at the Creys-Malville (Isère) site;
- **spent fuel from civil research reactors:** about **41 tHM (including 40 tHM of Phénix fast neutron reactor fuel)** at CEA sites and **1 tonne** at the La Hague site;
- **spent fuel from National Defence activities:** about **141 tonnes**.

Note:

Some spent fuel relating to National Defence activities (metal fuel for nuclear propulsion) might not be processed, in which case, it will be considered as waste.

Plutonium obtained from spent fuel after processing

The plutonium found in spent fuel assemblies is extracted during spent fuel processing. Uranium-based, light-water reactor fuel currently contains around 1% plutonium (by weight). This plutonium has energy potential.

It is dissolved, extracted and separated from the other materials contained in the spent fuel, then purified and conditioned to produce stable PuO_2 powder at the R4 and T4 facilities at the La Hague site.

Nowadays, plutonium is used to make **MOX fuel**, which contains depleted uranium and plutonium in the form of oxide $(U,Pu)O_2$ powder pellets. In France, 22 reactors are now licensed to use MOX fuel, which accounts for a little under 10% of the electricity generated in the country.

The plutonium extracted from spent fuel is owned by French and foreign electric utilities that are customers of AREVA's. In general, the plutonium is shipped to foreign customers as MOX fuel for use in reactors abroad.

As at 31 December 2007, some **82 tonnes of plutonium** were stored in France, including:

- 61 tonnes of Pu, separated and stored at La Hague;
- 10 tonnes of Pu currently being used to make MOX fuels (as PuO_2, mixed oxide $(U,Pu)O_2$ or in finished MOX assemblies);
- 9 tonnes of Pu in non-irradiated fast neutron reactor or MOX fuel assemblies outside fabrication plants, mostly on EDF reactor sites;
- around 2 tonnes of Pu stored at various CEA facilities.

Of this amount, **60 tonnes are French-owned.** Of these 60 tonnes, EDF's stock of separated Pu at La Hague accounts for about 29 tonnes - in other words, 3 years' worth of MOX fuel fabrication.

The plutonium stock figure relating to military activities is classified defence data.

Table 3.12 shows the quantities of radioactive materials at the end of 2007, as well as production forecasts for the end of 2020 and 2030. For "in-process" materials, in other words, materials that are only stored between two steps in an industrial process, the stocks forecast for 2020 and 2030 are given for information only, as they depend on the management solution that each company will choose according to the economic situation at the time it makes its decision.

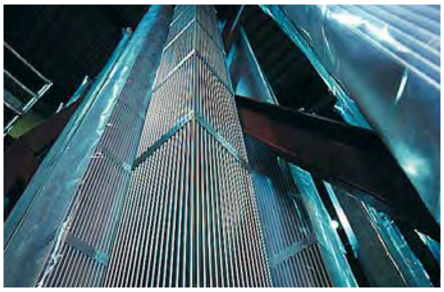
Production scenarios forecast for materials relating to the nuclear fuel cycle are the same as those used for waste (see Subchapter 3.1).

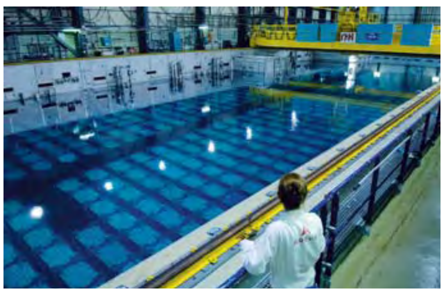
Table 3.12: Radioactive materials as at the end of 2007, 2020 and 2030

		2007	2020	2030	
Natural uranium from mining activities (tHM)		27,600	32,000	32,000	AREVA sites
		13	13	13	CEA sites
		27,613	**32,013**	**32,013**	**total**
Enriched uranium (tHM)		2,950	1,400	2,350	AREVA sites
		342	350	350	EDF sites
		14	14	14	CEA sites
		3,306	**1,764**	**2,714**	**total**
Recycled uranium (from spent fuel following processing) (tHM)		**21,180**	**36,000**	**49,000**	AREVA sites
Depleted uranium (tHM)		254,600	332,100	452,100	AREVA sites
		96	100	100	EDF sites
		124	124	124	CEA sites
		254,820	**332,324**	**452,324**	**total**
Thorium (t)		7,134	7,134	7,025	RHODIA site
		2,265	2,265	2,265	CEA sites
		9,399	**9,399**	**9,290**	**total**
SPM (suspended particulate matter) (t)		**21,672**	**0**	**0**	RHODIA site
Fuel in use at nuclear power plants and in research reactors (tHM)	UOX	**4,500**	**3,860**	**1,100**	EDF sites
	Recyled uranium	**80**	**290**	**0**	EDF sites
	MOX	**290**	**440**	**0**	EDF sites
	Research	**5**			CEA sites
Spent fuel awaiting processing	UOX (tHM)	3,584	3,500	1,200	EDF sites
		7,920	9,950	9,800	AREVA sites
		11,504	**13,450**	**11,000**	**total**
	Recycled uranium (tHM)	31	120	120	EDF sites
		220	900	1,200	AREVA sites
		251	**1,020**	**1,320**	**total**
	MOX (tHM)	308	420	650	EDF sites
		720	1,900	1,900	AREVA sites
		1,028	**2,320**	**2,550**	**total**
	Fast neutron reactor fuel (tHM)	**104**	**104**	**104**	EDF sites
	Experimental fuels (t)	41	0	0	CEA sites
		1	0	0	AREVA sites
		42	**0**	**0**	**total**
	National Defence fuels (t)	**141**	**230**	**298**	CEA/DAM
Plutonium from spent fuel after processing (tHM)		9	10	10	EDF sites
		2	2	2	CEA sites
		71	43	41	AREVA sites
		82	**55**	**53**	**total**

inventory according to activity sector

inventory according to activity sector





This chapter presents the radioactive materials and waste relative to each of the **twelve activity sectors** (as defined in Subchapter 1.3), recorded as on 31 December 2007, together with estimated amounts by 2020 and 2030.

The presentation for each sector is organised as follows:

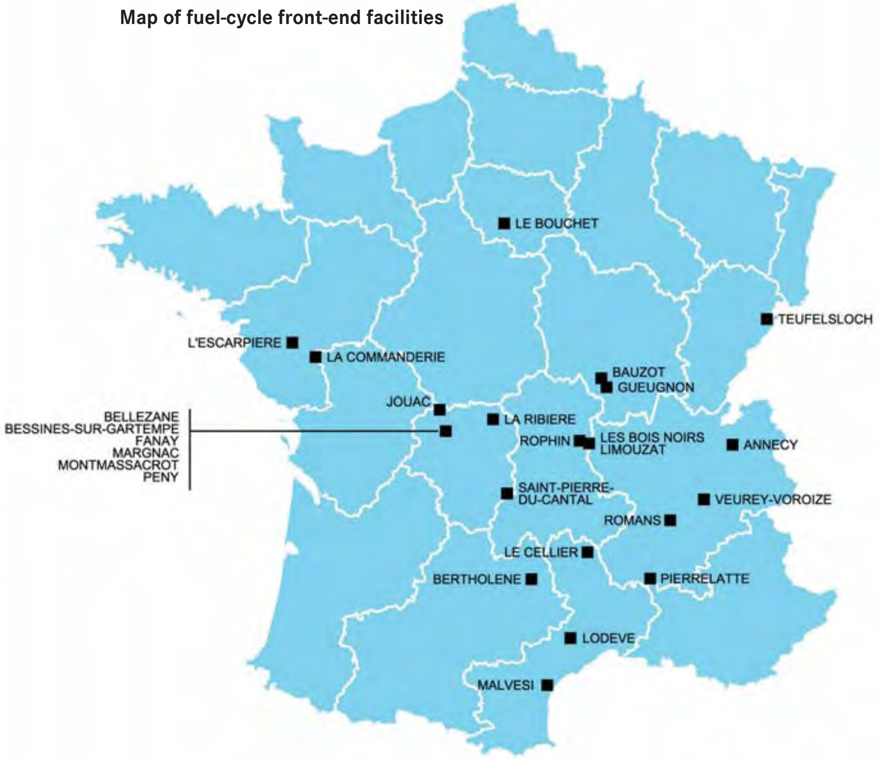
- **description of the activity sector** and, where applicable, the main sites in question;
- **the main types of waste** produced by the activity. The detailed report for each site where stocks are located as listed on 31 December 2007 is presented in the Geographical Inventory available separately;
- **scenarios adopted for forecasting purposes for the period 2008-2030;**
- **statements of waste produced by each management solution** for each activity. Stocks of waste for each management solution in 2007, 2020 and 2030, all sources combined (operating, dismantling and special operations) are thus presented;
- **estimated amounts of radioactive waste from dismantling operations** beyond 2030. This is restricted to facilities for which the operators have provided provisional data. It should be stressed that these are forward-looking assessments and that, while some facilities will be dismantled within a decade, it may be several decades before others are dismantled. Moreover, these estimates are likely to change as experience in such operations adds to our knowledge and waste treatment and conditioning techniques continue to improve, not to mention possible changes to regulations (see Section 3.1.2.5);
- **potential radioactive materials** related to each activity.

front end of the fuel cycle

4.1

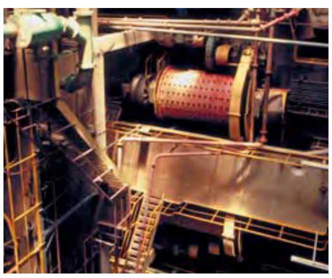
This activity sector includes facilities involved in the manufacture of nuclear fuel for electricity generation. The uranium and thorium ore processing mill at Le Bouchet, formerly run by the CEA, comes under this sector of activity; the waste produced by this plant is accounted for under the Research economic sector.

Map of fuel-cycle front-end facilities



Most of these fuel-cycle front-end facilities (see map above) have used or now use uranium (natural, then enriched), a very small percentage of which is found in facility operating waste.


Bellezane uranium mine


Ore crushing – France (AREVA)


Uranium pellets (FBFC plant in Romans)

4.1.1 Description of the activity

Ore mining and milling

Mining natural ore containing uranium (in open-cast or underground mines) has ceased in France.

Once the ore had been extracted, physical and chemical operations selectively separated the uranium and then concentrated it in a stable product (generally a uranium salt commonly known as *yellow cake*) that has a uranium content of around 75%. All the plants where these operations were carried out have now been shut down.

The tailings left over from uranium ore processing have been disposed of at or in the vicinity of the former mines and processing sites. The sixteen sites are Bauzot (Saône-et-Loire), Bellezane, Montmassacrot and Bessines-sur-Gartempe (all in the Haute-Vienne), Bertholène (Aveyron), Jouac (Haute-Vienne), La Commanderie (Vendée–Deux-Sèvres), La Ribière (Creuse), Le Cellier (Lozère), L'Ecarpière (Loire-Atlantique), Les Bois Noirs Limouzat (Loire), Lodève (Hérault), Rophin (Puy-de-Dôme), Saint-Pierre-du-Cantal (Cantal), Teufelsloch (Haut-Rhin) and Gueugnon (Saône-et-Loire).

Very-low-level radioactive waste from fuel-cycle front-end facility operations has also been disposed of at some of these sites.

Yellow cake concentrate on a belt filter

In addition, three sites belonging to La Crouzille Mining Division (COGEMA, formerly the CEA), were used in the 1970s and 1980s as dumps for very-low-level radioactive waste from various fuel-cycle front-end facilities: Fanay (Haute-Vienne), Margnac (Haute-Vienne) and Peny (Haute-Vienne).

Nineteen former mining sites are thus listed in the Geographical Inventory. In addition, there are also the ponds at the COMURHEX Malvési mill. In all, twenty sites used for on-site storage or disposal of uranium ore tailings or very-low-level radioactive waste produced by fuel-cycle front-end activities, are listed in the National Inventory.

The Le Bouchet site in Itteville (Essonne), the former location of a uranium and thorium ore processing mill operated by the CEA from 1946 to 1970, has been cleaned up. The waste from this cleanup operation has been accounted for under waste from this activity sector.

The uranium mine at Bellezane while still in operation

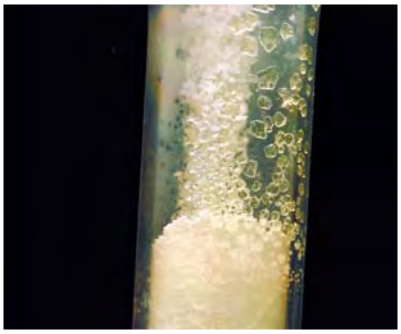
Le Bouchet site: cleanup (CEA)

Conversion

Conversion entails transforming uranium from mining activities into gaseous form at a temperature of 60°C. This state is essential for circulation in enrichment plants. The transformation process is divided into two stages:

- at the COMURHEX plant in Narbonne (Aude) where yellow cake is converted into uranium tetrafluoride
- and then at the COMURHEX plant in Pierrelatte (Drôme), where a fluoration process converts the tetrafluoride into uranium hexafluoride.

Crystals of UF_4 (uranium tetrafluoride)



Crystals of UF_6 (uranium hexafluoride) COMURHEX conversion plant, Pierrelatte

Enrichment

Natural uranium is mainly made up of two isotopes: uranium-238 and uranium-235. Uranium-235, which is fissile, is much less common in the natural state than uranium-238: it accounts for only 0.71% of natural uranium. The fuel now used in most nuclear reactors is uranium enriched to between 3 and 5% of uranium-235. Enrichment therefore entails increasing the uranium-235 content.

The enrichment process used at EURODIF's Georges Besse I facility is gaseous diffusion. Uranium, in the form of a gas, passes through diffusers, which separate the uranium-235 from the uranium-238 based on their difference in mass.

This generates two flows: one enriched in uranium-235 isotope and the other depleted in uranium-235 isotope.

View of the EURODIF Georges Besse I enrichment plant/Tricastin site

Fuel manufacturing

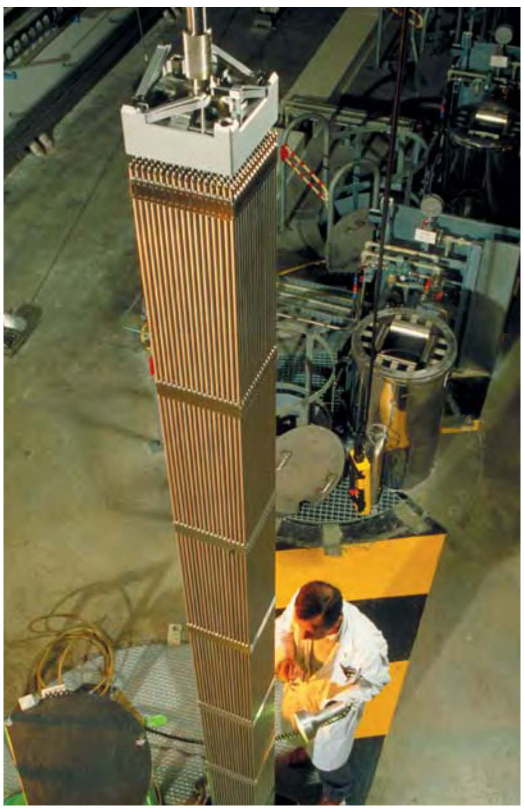
There are basically two types of fuel manufactured to produce electricity: UOX (uranium oxide) and MOX (mixed uranium and plutonium oxide).

UOX fuel (uranium oxide)

The enriched uranium hexafluoride is converted into uranium oxide powder then compacted into pellets to manufacture UOX fuel. The pellets are inserted into metal cladding to hold them in place, thus forming "fuel assemblies". Both these operations are carried out at the FBFC plant in Romans (Drôme).

MOX fuel (mixed uranium and plutonium oxide)

AREVA's MELOX plant located at the Marcoule site (Gard), has been manufacturing MOX fuel since 1995 using a process similar to that for UOX, but using a blend of uranium oxide and plutonium oxide powders. The plutonium is separated and conditioned by means of the spent fuel processing procedure used at La Hague. AREVA's Cadarache (Bouches-du-Rhône) facility, formerly operated by the CEA, also manufactured MOX fuel until July 2003.
The uranium used to manufacture MOX fuel is depleted uranium.
The plutonium comes from processing spent fuel (see Subchapter 4.3). Accordingly, manufacturing MOX fuel is conventionally included as a fuel cycle back-end activity rather than a front-end activity. This activity is described in the two corresponding subchapters on fuel cycle front-end and back-end activities, but the waste is only counted once.



Visual inspection of fuel assemblies (AREVA)

4.1.2 Waste produced

Uranium ore mining and milling activities produced about 50 million tonnes of very-low-level activity mine tailings, disposed of on site in accordance with the regulations in force at the time. This is equivalent to a volume of approximately 33 million cubic metres. Some waste from dismantling former ore processing facilities, together with a few low-level contamination drums, should be added to this figure – in all a few tens of thousands of cubic metres.

The chemical process used at the COMHUREX plant generates solid residue and liquid effluent. The latter contains very-low-level uranium-bearing solids and is stored in open-air settling ponds covering an area of 18 hectares. The settling ponds and the quantities of uranium stocked (approximately sixty terabecquerels) are described in the Geographical Inventory.

Conversion, enrichment and fuel manufacturing facilities produce low-level or very-low-level uranium-contaminated radioactive operating waste. More often than not, the contamination level in question is low enough for the waste to be compatible with and approved for acceptance at the CSFMA and VLLW disposal facilities. For this reason, it is accounted for under the LILW-SL and VLLW management solutions. It is usually conditioned in drums or container boxes.

The Le Bouchet plant is the only site in this activity sector to have produced LLW-LL category waste. The amount of radium bearing waste resulting from cleanup of this site is around 19,600 tonnes, i.e. approximately 11,900 m^3. It comes in the form of processing residue and sludge, contaminated by uranium and thorium. Over 6,000 m^3 of rubble from the CEA's Le Bouchet site accounted for as LLW-LL in the 2006 National Inventory has been recounted under the VLLW management solution.

VLLW handling at the CSTFA repository

Metal container boxes filled with solid waste (front end of fuel cycle)

4.1.3 Scenario for the period 2008-2030

The adopted scenario assumes that current industrial practices will continue.

It includes the phased replacement of the Georges Besse I plant by a new plant, Georges Besse II (see Box 4.1).

Box 4.1

GEORGES BESSE PLANTS

Every year, the Georges Besse I plant, operated by EURODIF, produces enriched uranium using the gaseous diffusion process . As of 2009/2010, the Georges Besse II plant, built on the Tricastin site, will gradually take over from the existing enrichment plant. This new plant will include two production units designed to achieve capacity of around 7.5 million SWU* by 2016/2018 and will deploy new gas centrifuge technology.

The existing plant will continue production at the same time, until it is closed down, scheduled for the beginning of the next decade. No significant impact, in terms of ordinary operating waste flow, is expected as a result of replacing the plant operated by EURODIF with the Georges Besse II plant.

Waste from dismantling the existing enrichment plant is counted in VLLW production forecasts for 2020 and 2030, of which it forms a significant percentage.

** Separative work unit (the measurement unit used for enrichment activities)*

4.1.4 General results for 2007, 2020 and 2030

Table 4.1 shows stocks of waste from the front end of the fuel cycle for each management solution in 2007, 2020 and 2030.

Table 4.1: Waste stocks at the end of 2007, the end of 2020 and the end of 2030 in m^3 conditioned equivalent

	2007	2020	2030
LLW-LL	11,867	11,867	11,867
LILW-SL	52,274 of which 51,425 in a repository	53,436	54,447
VLLW	44,458 of which 15,821 in a repository	170,078	266,067

4.1.5 Waste from dismantling operations after 2030

This waste, declared by AREVA, is shown in Table 4.2.

Table 4.2: Waste from dismantling operations after 2030 in m^3 conditioned equivalent

LILW-SL	5,000
VLLW	4,000

4.1.6 Radioactive materials

As at 31 December 2007, the following waste was in storage facilities:

- approximately 27,600 tonnes of natural uranium from mining activities, mainly at the AREVA sites in Tricastin (Drôme) and Malvési (Aude);
- approximately 2,950 tonnes of enriched uranium at the AREVA sites in Tricastin (Drôme), La Hague (Manche) and Romans (Drôme);
- approximately 149,100 tonnes of depleted uranium at the AREVA site in Tricastin (Drôme), and approximately 104,600 tonnes at the AREVA site in Bessines-sur-Gartempe (Haute-Vienne).

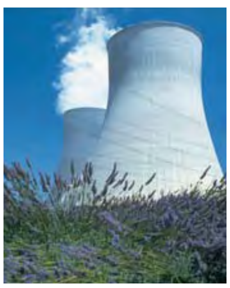
This depleted uranium comes from enrichment contracts on behalf of EDF and for other customers. Currently recycled for use in PWR reactors as a support for MOX fuel, depleted uranium has energy potential, mainly in specific nuclear reactor series, such as fast breeder reactors. Around 700 tonnes of depleted uranium corresponding to in-process inventory at conversion plants and fuel manufacturing plants were also in storage in France at the end of 2007.

Containers of UF_6 stored at the EURODIF Georges Besse enrichment plant/Tricastin site

Storing depleted uranium containers (AREVA Pierrelatte/Tricastin Site)

4.2 nuclear power plants

This activity covers all of EDF's nuclear power plants. France's nuclear power programme (see map below) currently consists of 58 nuclear power plants in operation at 19 geographic sites (see Table 4.3) and 9 plants that have been decommissioned (see Table 4.4).
In France, all the plants in operation are light water units, with 58 PWR plants (Pressurised Water Reactors that operate using enriched uranium) commissioned between 1977 and 2000. The end of 2012 will see completion of a new reactor, also in the PWR series, an EPR unit (Flamanville site). The PWR series has gradually replaced the former natural-uranium, gas-cooled, series (GCR) developed by the CEA in the 1960s and which have now all been decommissioned. EDF operated six of these plants (Chinon, Saint-Laurent-des-Eaux and Bugey), for which dismantling operations are underway. The resulting waste is accounted for under current electricity production activity.
On the other hand, the three GCR units at the Marcoule site are listed under the CEA's civil R&D activities in the case of the G1 reactor (see Subchapter 4.5) and under activities related to nuclear deterrence in the case of the G2 and G3 reactors (see Subchapter 4.10).


Cruas power plant

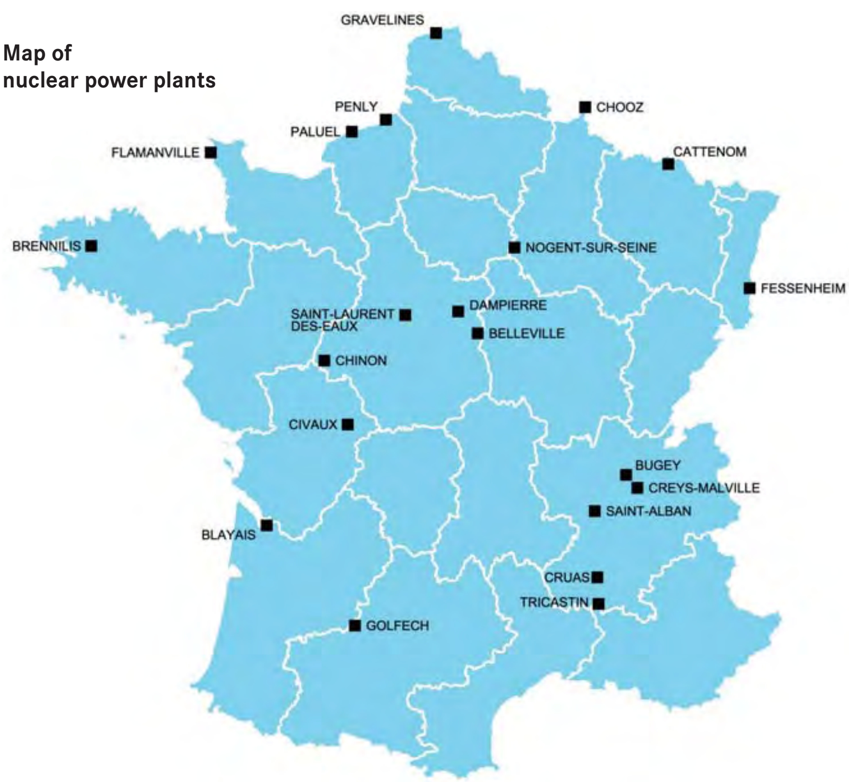

Bugey power plant


Saint-Laurent-des-Eaux power plant

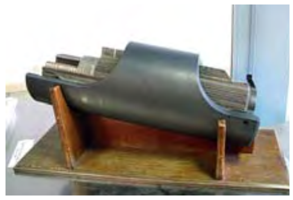

Flamanville power plant


Paluel power plant

Map of nuclear power plants



The first sodium-cooled fast neutron reactors (Rapsodie and Phénix), together with the EL4 prototype (the only electricity-producing reactor in the heavy water series, decommissioned in 1985), are counted under CEA civil R&D activities (see Subchapter 4.5). Current activity, however, includes waste from dismantling and fuel from the Superphénix fast breeder reactor, decommissioned at the end of 1998, together with waste from the Chooz A 300 Megawatt prototype PWR, decommissioned in 1991.



Cutaway view of a GCR fuel element

Table 4.3: Nuclear power plants in service

Site and date connected to the grid (first unit - last unit)	Number of units in operation - series	Net capacity per unit
Fessenheim (04/1977 – 10/1977)	2 - PWR	880 MWe
Bugey (05/1978 – 07/1979)	4 - PWR	910 / 880 MWe
Gravelines (03/1980 – 08/1985)	6 - PWR	910 MWe
Gravelines (03/1980 – 08/1981)	4 - PWR	890 MWe
Tricastin (05/1980 – 06/1981)	4 - PWR	915 MWe
Saint-Laurent B (01/1981 – 06/1981)	2 - PWR	915 MWe
Blayais (06/1981 – 05/1983)	4 - PWR	910 MWe
Chinon B (11/1982 – 11/1987)	4 - PWR	905 MWe
Cruas (04/1983 – 10/1984)	4 - PWR	915 MWe
Paluel (06/1984 – 04/1986)	4 - PWR	1,330 MWe
Saint-Alban (08/1985 – 07/1986)	2 - PWR	1,335 MWe
Flamanville (12/1985 – 07/1986)	2 - PWR	1,330 MWe
Cattenom (11/1986 – 05/1991)	4 - PWR	1,300 MWe
Belleville (10/1987 – 07/1988)	2 - PWR	1,310 MWe
Nogent-sur-Seine (10/1987 – 12/1988)	2 - PWR	1,310 MWe
Penly (05/1990 – 02/1992)	2 - PWR	1,330 MWe
Golfech (06/1990 – 06/1993)	2 - PWR	1,310 MWe
Chooz B (08/1996 – 04/1997)	2 - PWR	1,455 MWe
Civaux (12/1997 – 12/1999)	2 - PWR	1,450 MWe
19 Sites	58 units	

Table 4.4: Nuclear power plants being dismantled

Sites	Type	Number of units
Chooz	PWR	1 unit
Brennilis	EL	1 unit
Saint-Laurent-des-Eaux	GCR	2 units
Chinon	GCR	3 units
Bugey	GCR	1 unit
Creys-Malville	FNR	1 unit/fast breeder

4.2.1 Description of the activity sector

PWR fuel assemblies remain in nuclear reactors for a few years. Depending on its capacity, a reactor constantly draws on between 157 (900 Megawatt reactor) and 241 (1,650 Megawatt EPR) fuel assemblies, each of which contains around 500 kg of uranium. The fuel used is mainly uranium oxide (UOX) made from enriched natural uranium. However, twenty-two 900 Megawatt reactors are authorised to load mixed uranium and plutonium oxide (MOX) and two 900 Megawatt reactors (four in the near future) are already equipped to use fuel made of enriched recycled uranium, or ERU (see Section 4.2.6).

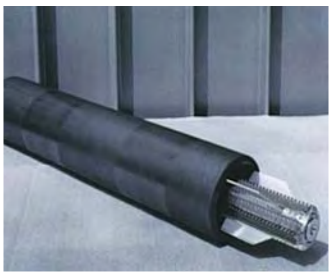
When it is removed from the reactor, spent UOX and ERU fuel contains 95% of uranium and around 1% of plutonium (5% in the case of spent MOX fuel). This spent fuel is not considered as waste but as radioactive material, given its residual energy potential. However, the remaining 4% of radioactive elements, isolated during processing operations, is HLW, described in Subchapter 4.3.

Apart from waste directly produced or resulting from processing spent fuel, operating a nuclear power plant and its regular maintenance involves the production of various kinds of waste (filters, resins, metallic or cellulosic waste, etc.), generally contaminated by the corrosion products activated and deposited within it.

Lastly, nine decommissioned reactors are producing cleanup and/or dismantling waste as progress is made on the various phases of the dismantling process.

This activity sector also includes the Irradiated Materials Workshop (AMI) at the Chinon plant, where assessments of irradiated structures are carried out.

Graphite sleeve and GCR fuel rod



Graphite sleeve and GCR fuel rod

Dismantling the Brennilis power plant

4.2.2 Waste generated by the activity sector

Spent fuel from the PWR series is not considered as waste since France has opted to recycle it. Since waste from fuel processing operations is counted under "fuel-cycle back-end" activity (see Subchapter 4.3), the only waste generated by nuclear electricity generation is waste from operating, maintenance and dismantling current facilities.

ILW-LL

This type of waste consists of scrap metal parts that have been directly subjected to neutron bombardment ("activated" waste). In the case of waste produced during operating, this mainly involves burnable poison rod assemblies (absorber rod assemblies whose role is to reduce core reactivity during the first operating cycle) and control rods (absorber rod assemblies in which the 24 absorber rods slide inside the fuel assemblies to control reactor power). In the case of the latter, strict criteria regarding wear means that they must be replaced several times throughout the unit's operating life. The waste produced during dismantling operations primarily implies metal structures which, like the rod clusters, present surface contamination associated with high activity in the mass. The conditioning hypothesis applied by EDF within the framework of the National Inventory is to cut up the metallic waste on site or at a central facility (ICEDA) and condition it by embedding it in cement inside concrete packages. The waste packages are then kept at storage facilities (see Section 4.2.3). This new facility should be in operation by 2013 at the Bugey site (01).

LLW-LL

The former GCR series generated LLW-LL "graphite" waste. A distinction is made between the components that surrounded the fuel (the "sleeves") and those that made up the reactor cores (the "stacks"). The dismantling programme initiated by EDF has not yet reached the stage of removing the stacks, which are still in place and will not be counted as waste until they have been dismantled. On the other hand, the sleeves, which have been removed and are in storage in silos at the Saint-Laurent site and at the Marcoule and La Hague sites (see Subchapter 4.3 regarding the latter two sites), are already counted as waste. The conditioning hypothesis applied for this existing and future waste is to embed it in cement inside concrete containers.

LILW-SL and VLLW

Operating at EDF's nuclear power plants and related maintenance activities generate waste - mainly VLLW and LILW-SL. This may involve equipment, filtration/purification residue (resins, filters or sludge, etc.), consumables (vinyl or cotton suits, etc.), as well as scrap parts (valves, tubes, etc.). This waste has been contaminated through contact with fluids - reactor coolant, ventilation air, etc. - which carries fission products and/or corrosion products activated when they pass through the core.

LILW-SL produced by EDF is all conditioned on-site at the power plants in concrete waste packages or in metal drums and container boxes which, respectively, are compacted or injected at the CSFMA low- and level-waste disposal facility (Aube), with the exception of incinerable waste and scrap iron that can be melted down, which is sent to CENTRACO plants (see Subchapter 4.4).

Concrete packages of cemented waste

VLLW produced by EDF varies in nature. This waste comes from the "nuclear areas" inside the power plants and has a very low level of radioactivity, in some cases, so low that it cannot be measured. A large proportion of this waste is generated by dismantling the earliest built nuclear power plants.

Some of the waste due to be generated in the short and medium term will be bulkier, in view of major maintenance operations scheduled for nuclear power plants, including the replacement of the reactor vessel heads on 54 reactors (operation in progress since the end of 1994, with the first head removed now placed in the CSFMA disposal facility in 2004) and the replacement of the steam generators for 26 reactors. Within the framework of this National Inventory, one of the options regarding these steam generators is to dispose of them at the CSFMA disposal facility.

Concrete packages of cemented waste

4.2.3 Scenario for the period 2008-2030

The scenario adopted factors in the industrial choices taken by EDF and which were presented to the French Nuclear Safety Authority (ASN) at the end of 2007, for the ten-year period 2007-2017. Up to 2017, current practices may be taken as firmly established. Beyond 2017, additional hypotheses must be defined, relating to reactor lifetime (the first 900 Megawatt PWR unit commissioned will be 40 years' old in 2017) and also to the future of nuclear energy programmes in the longer term.

To illustrate this, the following two scenarios are described in detail in Chapter 3.

- Scenario 1:
  the existing nuclear power plants in France are gradually being renewed and new units are being deployed; in time, "Generation IV" units will be deployed, making it possible, within the scope of this hypothesis, to recycle all the plutonium produced by existing plants.
- Scenario 2:
  nuclear electricity production is limited to the plants that already exist, which means that fuel processing can stop in 2019, with a view to having zero stocks of separated plutonium (i.e. not including plutonium contained in spent fuel) at the time that the last MOX-fuelled unit is decommissioned in 2030.
  Interim scenarios, in which nuclear power generation continues, but by means of nuclear power plants that afford more limited possibilities for recycling plutonium than those planned by the industrial operators thanks to so-called "Generation IV" technology, may also be considered. This may lead to recycling only the plutonium contained in UOX fuel, and not that contained in MOX fuel. The two scenarios mentioned above relate to two contrasting situations defined for the purposes of illustration only. They will be used in estimating "committed waste" (see Appendix 2). Only the first scenario has been adopted in forecasts for the end of 2020 and the end of 2030.
- There should be more extensive recycling of uranium and plutonium. Thus, the number of units that work with (ERU) fuel made from recycled uranium will increase from 2 to 4 by 2009/2010. Once they have achieved balance, these 4 units loaded entirely with ERU assemblies will, per year, recycle nearly 600 tonnes of uranium from the 800 tonnes recovered during spent fuel processing. For this National Inventory, the quantity of MOX fuel used during the period 2008-2020 is assumed to be constant and equal to 100 tHM/year: this is in line with current recycling throughput which, in light of processing throughput which is also assumed to remain constant (850 tHM per year) and given the new management process implemented for MOX fuel, will make it possible to stabilise plutonium stocks. Nonetheless, in the medium term, EDF is planning to increase recycling flow and increase the number of units authorised to use MOX fuel from 22 to 24, provided it is granted the required administrative licences. This increased plutonium recycling will go hand-in-hand with an increase in processing flow, without any impact on the total quantity of waste (which is related to NPP operation and energy production level). This increased processing flow will nonetheless entail speeding up the re-

Metal container box filled with cemented waste

placement of spent fuel with conditioned HLW and ILW-LL. So, in 2020, the mass of spent fuel may be slightly lower than the estimates given in this National Inventory (and slightly higher in the case of the resulting waste).

- Fuel processing concerns enriched natural uranium oxide fuels (UOX) which can be recycled industrially in existing PWR units. Continuous improvements in the performance of these fuels will result mainly in increased enrichment and combustion rates, albeit with a reduction in the energy potential of the materials (uranium and plutonium) extracted following processing. As a result, mixed uranium and plutonium oxide fuel (MOX) and enriched recycled uranium fuel (ERU) I products will see an increase in their content of enriched plutonium and uranium, respectively, to maintain their energy characteristics. The feasibility of recycling MOX and ERU fuels has now been demonstrated, at AREVA's facilities. Nonetheless, the benchmark industrial management solution for such fuels consists in them being recycled in "Generation IV" units and, bearing this in mind, storing them will create a strategic reserve to supply the future generation of nuclear power plants when the time comes.
- Dismantling operations, some of which have already been initiated by EDF, will be pursued throughout the period 2008-2030. The units involved are Brennilis, Chooz A and Creys-Malville (Superphénix), together with the earlier gas-cooled (graphite-moderated) reactors, namely Chinon A, Bugey 1 and Saint-Laurent A. EDF has committed to a full dismantling programme regarding all first-generation power plants, which should be more or less completed by 2030 for all the plants except Saint-Laurent A.
- New facilities scheduled for construction by 2020 include ICEDA (conditioning and storage facility for activated waste), which was subject to public enquiry in 2006 and for which EDF has filed the construction licence application, which is now being examined. Operating this facility should only generate very small quantities of waste; this waste is not counted in this National Inventory since it is "uncommitted" waste. However, all the waste produced by EDF plants which is intended for conditioning at ICEDA is listed under this activity sector.

4.2.4 General findings for 2007, 2010 and 2020 and 2030.

Table 4.5 shows stocks of waste from the "Nuclear power" activity sector for each management solution in 2007, 2020 and 2030.

Table 4.5: Waste stocks at the end of 2007, the end of 2020 and the end of 2030 in m^3 conditioned equivalent

	2007	2020	2030
ILW-LL	966	1,712	2,552
LLW-LL	9,061	35,061	52,061
LILW-SL	286,590 of which 272,894 in a repository	375,735	448,595
VLLW	42,197 of which 25,445 in a repository	159,597	207,297

4.2.5 Dismantling operations after 2030

The volumes related to dismantling after 2030 include, first, a very small amount remaining from dismantling nuclear power plants that have now been decommissioned, but mainly to the dismantling of the 58 nuclear power reactors currently in operation. EDF estimates the following volumes (Table 4.6):

Table 4.6: Dismantling after 2030 in m^3 conditioned equivalent

ILW-LL	6,000
LLW-LL	0
LILW-SL	249,000
VLLW	468,000

4.2.6 Radioactive materials

Stocks at the end of 2007

As at 31 December 2007, the following materials were stored at EDF sites in the form of new fuel assemblies:

- 342 tHM of enriched uranium, in the form of 667 UOX fuel assemblies;
- 96 tonnes of depleted uranium and 9 tonnes of plutonium in the form of 72 MOX fuel assemblies and 455 FBR assemblies from Superphénix, respectively, and which were never loaded since the unit was decommissioned in 1998.

Note: at the beginning of 2008, the Italian partners decided to retrieve, in separated form, the share of the plutonium which they had supplied: as a result, France owns all the plutonium contained in the Superphénix assemblies.

Since the time that the first nuclear power plants were commissioned in the 1960s, EDF has unloaded 6,855 tonnes of spent fuel from the GCR series, and a little over 26,000 tonnes from PWR series. Except in specific cases, the spent fuel is processed as it is removed from the reactor, following an average ten years' cooling in spent fuel pools at the site.
The stocks of fuel that is either being used or that is spent as at 31 December 2007 break down as follows:

- 4,870 tML[1] PWR fuel contained in the reactors, (Table 4.7)
- 12,783 tHM of spent fuel from PWRs stored underwater to cool down in the power plant pools or at the La Hague plant (Table 4.8). As at 31 December 2007, all fuel from GCRs belonging to EDF had been processed, together with 13,300 of UOX fuel from PWRs. In accordance with EDF's industrial strategy, processing ERU and MOX fuel has not yet begun.

Table 4.7: Fuel used at EDF nuclear power plants, in tHM at the end of 2007

Enriched natural uranuim oxide (UOX)	4,500
Enriched recycled uranium oxide (ERU)	80
Mixed uranium and plutonium oxide (MOX)	290

- Spent fuel from the Superphénix fast breeder reactor (see *note* above): 104 tHM in the form of 588 fuel assemblies are currently stored at the Creys-Malville site (Isère).

Table 4.8: Spent fuel produced by EDF in tHM, pending processing at the end of 2007

Enriched natural uranuim oxide (UOX)	11,504
Enriched recycled uranium oxide (ERU)	251
Mixed uranium and plutonium oxide (MOX)	1,028

- Fuel from the former EL4 Brennilis plant: 5,400 fuel assemblies (49 tonnes) are currently stored at the CASCAD facility in Cadarache (Bouch-

1 Tonnes of heavy metal.

es-du-Rhône). Since December 2008, EDF has been responsible for the cost of the recovery and long-term management operations related to this fuel.

Projected stocks up to 2020 and 2030

The amount of spent fuel stored pending processing (Table 4.9) varies depending on the amount unloaded from reactors each year (which in turn depends on electricity supplied to the network and on fuel performance) and on the amount processed at the La Hague plant (Section 4.3.3). On this subject, current policy entails only processing fuel that can be industrially recycled in existing nuclear power plants. Given the points covered in Section 4.2.3, the amount of ERU and MOX fuel unloaded from reactors stored in the pools at the power plants and at the La Hague plant (see Section 4.3) will therefore build up. The future of fuel from fast neutron reactors, stored at Creys-Malville, will be examined in line with that of MOX fuel.

Table 4.9: Spent fuel awaiting processing (in tonnes of heavy metal) at the end of 2020 and the end of 2030

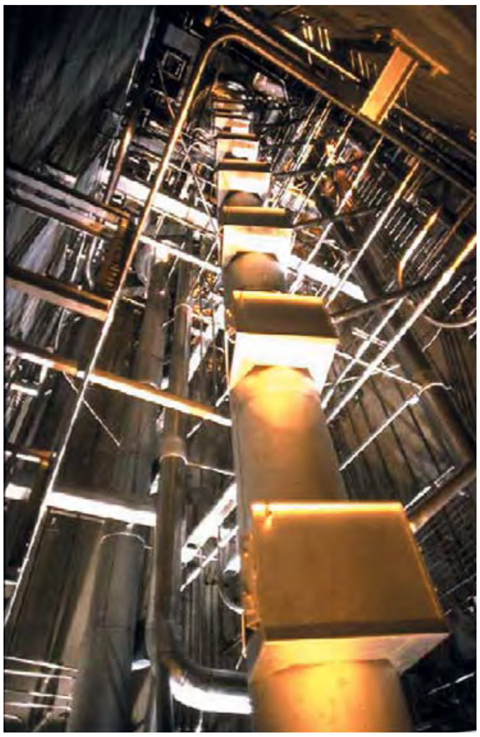
	2020	2030
UOX	13,450	11,000
ERU	1,020	1,320
MOX	2,320	2,550
FNR	104	104

Pool E, storing spent fuel at AREVA's La Hague processing plant

back end of the fuel cycle

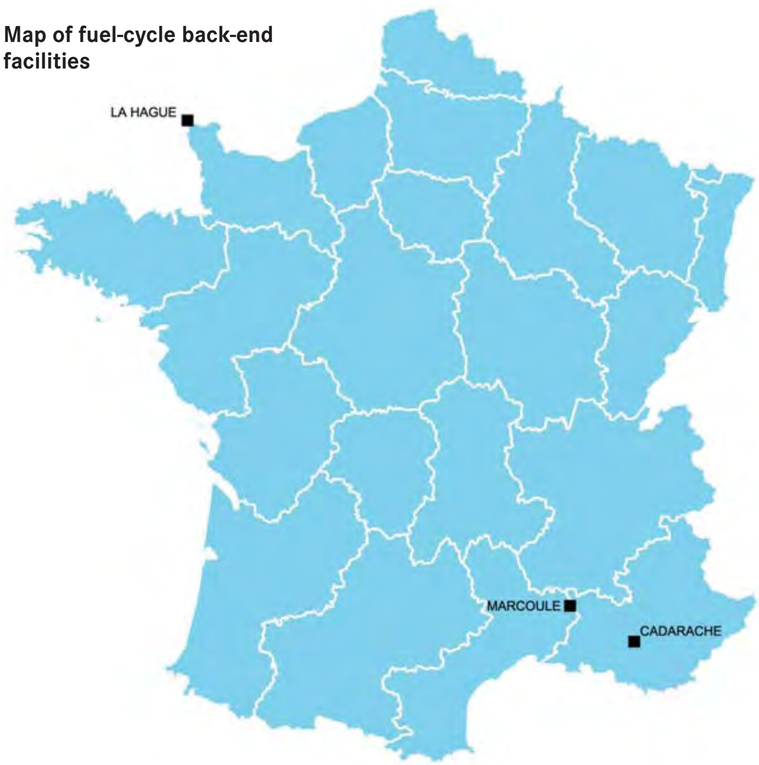
4.3

Fuel-cycle back-end activities include processing spent fuel and manufacturing fuel using the materials produced from processing spent fuel (uranium and plutonium). Three economic sectors are involved: Nuclear power plants, Defence and Research.



AREVA pulsed columns at La Hague

Map of fuel-cycle back-end facilities



4.3.1 Description of the activity

When fuel has been irradiated in a nuclear reactor, it still contains 96% of recoverable energy materials, uranium and plutonium, leaving 4% of fission products and minor actinides considered as waste. The spent fuel processing procedure consists in retrieving these materials and conditioning the ultimate waste. The operations performed in a processing plant can be broken down into three stages:

- spent fuel assemblies are received and stored in pools to cool down (for several years) prior to processing;

- processing spent fuel assemblies:
  - spent fuel assemblies from PWRs are mechanically sheared into sections measuring around 35mm (known as "hulls")[2];
  - nitric acid is used to chemically dissolve the spent fuel in the hulls;
  - the dissolved uranium and plutonium are separated by chemical extraction and purified, then conditioned;
- the waste is treated and conditioned in stable forms appropriate to the activity and radioactive half-life of the elements they contain.

In the National Inventory, fuel-cycle back-end activities also include the manufacture of MOX fuel (see Subchapter 4.1), which makes use of the plutonium separated by spent fuel processing.

Aerial view of the Marcoule plant

Sites involved in the activity

The UP1 plant at Marcoule

The first French spent fuel assembly processing plant, **UP1**, was commissioned at the Marcoule site in 1958 and decommissioned at the end of 1997. It was operated first by the CEA and then by COGEMA (from 1976, when the company was set up; and now AREVA) for military (plutonium extraction for weapons) and then civil purposes (processing fuel assemblies from the GCR series and PHENIX and for experimental processing activities).

Cleanup operations are now underway. These include three programmes:
- decommissioning the facilities;
- dismantling (or demolition) the facilities;
- recovering and conditioning the legacy waste related to UP1 activity, which is stored at special facilities. Since the end of 2004, the CEA has been project owner for these programmes. They are due to be completed by 2035.

Aerial view of AREVA's spent fuel processing plant at La Hague

The plants at La Hague

In 1966, a second spent fuel assembly processing plant was commissioned at the La Hague site: **UP2-400**. Just like UP1, this plant was run by the CEA until 1976, and then by COGEMA (now AREVA) as soon as the company was set up. The UP2-400 plant had initial annual capacity of 400 tonnes of fuel and started by processing spent fuel assemblies from the GCR series.

In 1969 France adopted the PWR series to take over from GCR, The UP2-400 plant was therefore adapted to process PWR spent fuel assemblies (at the High Activity Oxide (**HAO**) unit commissioned in 1976).

AREVA's La Hague UP2 400 pool (storage pool for hulls and end caps)

Between 1976 and 1987, the UP2-400 plant alternated between processing spent fuel assemblies from both the GCR and PWR series.

Since then, UP2-400 has been exclusively used for fuel from PWR units, while the Marcoule UP1 plant continued to process other types of fuel assembly.

In the early 1980s, AREVA began building two new similar plants with equivalent capacity (800 tonnes/year) to cater for French and foreign demand.
- **UP3**, initially exclusively dedicated to spent fuel supplied by foreign customers (started up in November 1989);
- **UP2-800**, commissioned in August 1994, which seamlessly took over from the UP2-400 plant, which has since been shut down.

Storage area at AREVA's UP2 800 R7 vitrification facility at La Hague

2 The initial operation regarding fuel from the former GCR series consisted in "decladding", i.e. removing the magnesium cladding either chemically (dissolving) or mechanically (peeling) depending on the process implemented.

Storing solid waste packages at the compacting yard in Marcoule

Inspecting vitrified waste packages at the R7 vitrification facility. AREVA's La Hague UP2-800 spent fuel processing plant

Spent fuel is currently processed alternately at the UP2-800 and UP3 plant facilities at La Hague.

MOX fuel manufacturing plants

Production of MOX fuel at Cadarache has now been stopped. This production (40 tonnes/year) has been diverted to the MELOX plant at the Marcoule site. The initial pilot operations to dismantle the Cadarache plant started in 2007. The MELOX plant started operating in 1994. Its current capacity is 190 tHM of MOX fuel per year (heavy metal mass), intended for French and foreign light water units.

4.3.2 Waste produced

The waste types are as follows:

- waste directly produced from spent fuel;
- waste related to operating and maintenance at MOX fuel manufacturing or processing facilities.

Hulls and end caps at AREVA's compacting facility at the La Hague site

Compacted package ILW-LL (CSD-C)

Vitrified package for HLW (CSD-V)

Waste directly produced from spent fuel

The ultimate waste contained in the spent fuel falls into two categories:

Fission products and minor actinides

At the La Hague plant and at the vitrification facility in Marcoule, these are separated from the uranium and plutonium, and then calcinated and incorporated into glass matrices.

At the R7 and T7 workshops at La Hague, the glass is then poured into standard vitrified waste containers (CSD-V); at the Marcoule site, the process is similar to that used at La Hague.

This process is used to condition the radioactivity in a compact, durable and confining form. These are HLW packages.

Cladding waste

As regards light water units, cladding waste consists of the metal components (cladding tubes, spacer grids and end caps) used to contain and assemble the fuel pellets. Today, they are decontaminated, compacted and conditioned at La Hague in standard compacted waste containers (CSD-C) which are geometrically similar to CSD-Vs and are known as "hulls and end caps". They are ILW-LL packages.

For a short time, 1990-1995, the light water sector fuel assembly cladding waste processed at La Hague was conditioned by cementation into 1.5m^3 metal drums.
Most of the GCR-series cladding waste, whose spent fuel has been processed at La Hague and Marcoule, consists of graphite sleeves (VLW-LL) and magnesium cladding (mainly ILW-LL), which are in storage awaiting conditioning.

Waste from facility operating and dismantling

This includes:

Maintenance operations waste (tools, work gloves, filters, used materials, film and vinyl, etc.) or pool water treatment waste (resins), which is conditioned in different types of container depending on its nature, activity level and management solution.

The waste is mainly:
- ILW-LL, compacted in CSD-C packages at La Hague in the case of hulls and end caps or in S5 packages in the case of predominantly alpha waste, or embedded in cement (widely-used conditioning process before the ACC hull compacting facility opened) or bituminised (sludge conditioned using bitumen at Marcoule or La Hague). It should be noted that since 1995, AREVA has managed effluent using a process that significantly limits the production of sludge conditioned by bituminisation. For so-called "STE2" sludge generated by operating the UP2-400 plant prior to 1991, AREVA is looking into a process for drying and compacting the sludge before placing it in stainless steel drums;
- LILW-SL, generally compacted and embedded in cement, or, occasionally, incinerated or melted down at the CENTRACO plant;
- VLLW, conditioned in big-bags (earth and rubble), metal drums or container boxes.

Dismantling waste

This currently involves the Marcoule plant (UP1) and, in the short term, a section of the UP2-400 plant at La Hague. In addition to these two spent fuel processing and recycling facilities, the dismantling of the MOX plant in progress at the Cadarache site should be mentioned. The waste generated is mainly LILW-SL and VLLW.

ADT, storage of CO and C1 drums from AREVA's AD2 facility at the La Hague site

STE3 effluent treatment station. AREVA's drum-filling carousel at the La Hague site

4.3.3 Scenario for the period 2008-2030

The scenario adopted for the period 2008-2030 is mainly based on the following hypotheses.

It is presumed that the quantity of EDF spent fuel processed at the La Hague plant will be stable throughout the period, at around 850 tonnes/year. The throughput of plutonium separated at the processing plant will therefore remain the same as that which is expected to be recycled by manufacturing mixed oxide (MOX) fuel. It should be noted that an increase in this throughput is currently being considered. The quantity of fuel processed annually will thus rise to around 1,000 tonnes/year. Given the time lag between data acquisition for the National Inventory and its publication, it has not been possible to factor this increase into the current edition. It will however be included in future updates.

The hypothesis that MOX fuel may be processed in combination with UOX and ERU is considered as of 2031. EDF's current industrial programme makes UOX fuel processing a priority.

The decommissioned Marcoule UP1 and La Hague UP2-400 fuel processing facilities will be cleaned up and dismantled by the end of 2030. Dismantling of the MOX fuel manufacturing plant in Cadarache will be complete by 2013.

It should be remembered that the reconditioned waste from future recovery and conditioning operations, such as those described below, is, by agreement, accounted for in the volumes existing on 31 December 2007, according to the volume of the final waste packages.

Scenario for the period 2008-2030 at the La Hague site

First, we should mention the planned vitrification of fission product solutions, known as UMo (uranium molybdenum, from GCR fuel), which are currently in storage. These solutions cannot be vitrified using the facilities currently available at La Hague, given their high molybdenum content. Research and development studies will result in implementation of a suitable vitrification process, consisting in producing the glass in a cold crucible. Around 900 packages will be produced, for a volume of 158 m^3. Vitrification of UMo solutions is due to begin after 2010.

Recovery and conditioning operations on legacy waste in storage, for the most part produced in the 1970s and 1980s, are planned during this period. In accordance with the French Act of 28 June 2006, owners of ILW-LL are required to ensure that is has been conditioned by 2030.

The main operations involve sludge produced by treating effluent, stored at the STE2 facility, together with waste stored in HAO silos, at the hull storage facility (SOC, Stockage Organisé des Coques) and in Silos 115 and 130.

STE2 sludge comes from operations at the UP2-400 plant up to the end of the 1980s; it is now stored in 7 semi-underground silos at the former effluent treatment station No.2 (STE2), except for part of the sludge from one of the silos (Silo 14), which was immobilised in bitumen at the end of 2007, leading to the production of 340 drums (81 m^3). In 2008, the French Nuclear Safety Authority (ASN) banned bituminisation of sludge at the STE3 facility. Insofar as regards the remaining sludge in Silo 14 and the sludge stored in the other silos, AREVA is, as a result, planning an alternative conditioning process to bituminisation. The conditioning process currently being looked at includes initial drying operations, followed by compacting the sludge and placing the compacted pellets in stainless steel containers.

The HAO silo is an underground pond containing cladding waste (hulls and end caps) directly produced from spent fuel assemblies from light water units which were processed at the HAO facility at the UP2-400 plant between 1976 and 1990, together with operating waste from this facility (carrier lids, resins from HAO pool water treatment, fines and miscellaneous technological waste). The strategy for retrieving and conditioning the waste stored in the HAO silo involves sorting the waste according to size and nature. This should result in the production of CSD-C packages (hulls and end caps, together with metallic technological waste) and cemented packages for small-size ILW-LL (resins and fines).

The hull storage facility (SOC, Stockage Organisé des Coques) consists of three pools (S1, S2 and S3) in which spent fuel cladding waste processed at UP2-400 has been stored under water in carriers since 1988. Hulls and end caps from the SOC facility, together with parts of the carriers and their lids that are unsuitable for surface disposal, will be conditioned in CSD-C packages. Parts that can be disposed of in surface facilities will be conditioned in fibre-reinforced concrete hulls.

Silo 115 contains three 400 m^3 cylindrical tanks. These tanks contain cladding waste produced directly from GCR fuel assemblies processed at the UP2-400 plant between 1966 and 1974 (magnesium cladding and graphite sleeves). Silo 130 is an underground bunker consisting of two 3,000 m^3 cells, only one of which contains waste. This waste is a) waste directly produced from GCR fuel cladding processed at the UP2-400 plant between 1973 and 1990 and b) miscellaneous technological waste, water, earth and rubble.

The GCR waste in these silos, which is LLW-LL, must be conditioned in concrete packages. There are also a number of operating waste items which are, *in principle*, due to go to a surface repository.

Recovery operations are due to start in 2012 in the case of waste stored in the HAO silo and Silo 130, in 2016 in the case of waste stored in the SOC facility and after 2026 for waste stored in Silo 115.

The Attila cell at the La Hague site contains approximately 130 x 200-litre drums, half of which contain ILW-LL, while the other half contain LILW-SL. This waste is also scheduled to be recovered and reconditioned.

Lastly, there is the recovery of miscellaneous waste (resins, graphite powder, etc.) stored in the UP2-400 plant's settlement tanks, and also mineralisation treatment of used solvents from the same plant. The waste will be conditioned in graphite-reinforced concrete packages for LLW-LL, in fibre-reinforced concrete hulls for LILW-SL, and in cement-immobilised packages for ILW-LL.

This waste will all have been conditioned by the end of 2030. Some conditioning operations must first be approved by the French Nuclear Safety Agency (ASN).

Scenario for the period 2008-2030 at the Marcoule site

Cleanup of the Marcoule site will continue during the period 2008-2035.
Part of the waste could be sent for surface disposal, subject to acceptance by Andra.
In the case of other waste (HLW and ILW-LL), the objective is to group it together at special facilities.
HLW vitrified waste packages (stored in shafts) are to be grouped together at the Marcoule vitrification facility (AVM).
The EIP multipurpose storage facility, commissioned in Year 2000 to store ILW-LL, is mainly used for bituminised waste. At the end of 2007, all the bituminised drums initially stored in the underground cells in the North Sector at Marcoule had been recovered, reconditioned and stored in the EIP. The bituminised drums stored in bunkers at the liquid effluent treatment station (STEL) are to be recovered in stages.
Cladding waste containing magnesium (spent fuel cladding from GCR units) is stored in 17 cells. From 2021, this will be recovered and conditioned in 223-litre drums in line with the CEA's current hypothesis, and then stored at the storage facility pending shipment for disposal (the IAE, Installation d'Attente d'Expédition), which is due to be operative in 2016.
By 2020, around half the recovery and conditioning operations regarding legacy waste stored at the site will have been completed, together with most of the facility shutdown and dismantling operations.

View of the multi-purpose storage facility (EIP) at Marcoule

The AREVA plant in Cadarache

Pilot dismantling operations started in 2007. The authorisation decree, which is expected to be granted in mid-2009, will mark the start of dismantling operations, which should be complete by 2013.

4.3.4 General results for 2007, 2020 and 2030

Stocks of waste as at 31 December 2007

Waste produced at the La Hague site

Table 4.10 shows the different types of waste packages produced from spent fuel at the La Hague plant, part of which will be returned to AREVA's foreign customers. For each type of package, the following information is given:

- the number of containers as at 31 December 2007;
- the number of containers of waste awaiting conditioning;
- France's share of all this waste, the remainder of which will be shipped to AREVA's foreign customers, in accordance with the Law and with customer contracts (see Appendix 1).

Table 4.10: Packages of waste from spent fuel, part of which will be returned to AREVA's foreign customers

	Total number of packages stored as at 31 December 2007	Estimated total number of waste packages to be produced from unconditioned waste in storage as at 31 December 2007	Total volume of waste packages produced or to be produced from waste stored as at 31 December 2007 (m^3)	Estimated French-owned share of spent fuel processed prior to 31 December 2007 (%)
CSD-V (HLW)	9,088	603	1,696	87.7
CSD-C (ILW-LL)	6,089	8,186*	2,612	50.9
CSD-B	0	381	7,942	93.2
Bituminised drums	10,912	0		
"C5" package	0	20,300		

* CSD-C waste packages contain hulls and end caps as well as operating and maintenance waste.

The total stock of waste produced by the La Hague processing plant at the end of 2007 is given in Table 4.11.

Table 4.11: Stocks of waste produced at the La Hague site at the end of 2007 in m^3 conditioned equivalent

HLW	1,650
ILW-LL	19,171
LLW-LL	4,952
LILW-SL	156,213
VLLW	17,113

Waste produced at the Marcoule site (UP1 plant)

These stocks, as at the end of 2007, are shown in Table 4.12.
34,456 bituminised drums were recorded in the 2006 National Inventory under the LILW-SL management solution, and the possibility of disposing of this waste at the LILW disposal facility (CSFMA) was under examination at the time of their declaration for that National Inventory. In 2006, Andra refused the application to dispose of 31,894 of these waste drums at the CSFMA. Reclassification under the LLW-LL management solution is one of the options currently being studied for these 31,894 bituminised drums. The possibility of increasing the number of drums to 40,000 (the additional 8,106 drums come under the ILW-LL management solution in this Inventory) will be examined in view of the results of the study that is currently in progress.

Table 4.12: Stocks of waste produced at the Marcoule site at the end of 2007 in m^3 conditioned equivalent

HLW	558
ILW-LL	10,684
LLW-LL	37,874
LILW-SL	103,329
VLLW	14,951

Combining the two tables above gives the following total volume, in m^3, of French waste from the back end of the fuel cycle (Table 4.13):

Table 4.13: Total waste stocks at the end of 2007 in m^3 conditioned equivalent

HLW(*)	**2,208**
ILW-LL	**29,855**
LLW-LL	**42,826**
LILW-SL	**259,542** including 231,681 already in a repository
VLLW	**32,064** including 3,203 already in a repository

(*)This refers to all French waste produced or conditioned at the processing plants, regardless of who the customer is (EDF, CEA, etc.). However, waste produced by the CEA as part of its experimental activities on processing, and at its own facilities, is accounted for in Subchapter 4.5.

Production from 2008 to 2030

The main hypotheses adopted for assessing the volume of waste at the end of 2020 and at the end of 2030 are described in detail below.

Waste directly produced from spent fuel

The following hypotheses have been adopted for the period 2008-2030 for estimating the quantities of waste directly produced by processing EDF spent fuel at La Hague in the future:

- an average of 0.13 m^3 of HLW (CSD-V vitrified waste packages) per tonne of fuel processed during the period (an average of 0.74 CSD-V per tonne of fuel, exterior volume of the CSD-V: 175 litres); this ratio mainly depends on the burnup rates of the spent fuel delivered by EDF, which will gradually increase over the period in question, as well as on the expected improvement in the amount of fission products allowed in vitrified waste packages;
- 0.156 m^3 of cladding waste (ILW-LL) per tonne of processed fuel This average quantity corresponds to production of 0.85 of a compacted waste package (CSD-C: 183 litres) per tonne, which includes both fuel assembly cladding (hulls and end caps) and part of facility operating waste (also compacted in CSD-Cs).

Waste related to facility operating and dismantling:

- approximately 1,400 ILW-LL reinforced fibre-concrete packages (CBFC'2) with volume of 1.18 m^3, containing waste related to facility operating, are expected to be produced during the period 2008-2030. Over this period, annual production of CBFC'2 packages will gradually decrease in view of AREVA's plans to extend compacting to this type of waste at the ACC facility. By the 2030 dateline, there should be around 40 CBFC'2 packages/year (excluding waste recovery and conditioning operations, which are accounted for in the 2007 stocks);
- it is assumed that 4,000 S5 metal containers (ILW-LL) will be produced over the same period, to condition miscellaneous waste, mainly contaminated by alpha emitters;
- the volume of bituminised sludge produced through effluent treatment at STE3 (ILW-LL) is low compared with the existing stock (around **1,400 drums** throughout the period).

Average production of LILW-SL over the period is around **2,000 m^3/year** (500 m^3 of which is related to facility dismantling) at La Hague and **5,000 m^3** (3,000 m^3 of which is related to facility dismantling) at the Marcoule site. Waste stocks in existence at the end of 2020 and end of 2030 are shown in Table 4.14.

Table 4.14: Waste stocks at the end of 2020 and at the end of 2030 in m^3 conditioned equivalent

	2020	2030
HLW	3,594	4,975
ILW-LL	33,766	36,520
LLW-LL	42,826	42,826
LILW-SL	349,941	419,644
VLLW	95,252	144,757

4.3.5 Waste from dismantling operations after 2030

This waste is related to dismantling the UP2 800 and UP3 plants at La Hague and the MELOX plant. Waste related to dismantling the UP1 plant in Marcoule is counted in Subchapter 4.5 together with waste related to dismantling other CEA facilities.

Table 4.15: Dismantling waste after 2030 in m^3 conditioned equivalent

ILW-LL	3,000
LILW-SL	23,200
VLLW	30,500

4.3.6 Radioactive materials

Recycled uranium has a slightly higher fissile uranium-235 content than natural uranium. Following additional enrichment, it is converted into enriched recycled uranium (ERU), which can be used in conventional fuels. Two of the reactors at the Cruas power plant (EDF) now use it (see Subchapter 4.2.1). Some 35 tonnes of this type of fuel is manufactured every year from approximately 280 tonnes of recycled uranium, i.e. approximately 35% of annual production based on processing EDF fuel.

The remainder of the recycled uranium is stored in various chemical forms: uranium oxide (U_3O_8), uranium hexafluroride (UF_6), or in the form of uranyl nitrate.

As at 31 December 2007, **21,180 tonnes of recycled uranium (including 2,770 tonnes of foreign-owned recycled uranium)** was mainly (except for small amounts of uranyl nitrate in-process, which has yet to be converted) stored at the AREVA sites in Tricastin (26), and at the La Hague site (50).

All of this uranium has been separated through spent fuel processing implemented at La Hague, for fuel from light water units and GCR units alike.

As at 31 December 2007, there were approximately **82 tonnes of plutonium** stored in France, including:

- 61 tonnes of separated Pu stored at La Hague;
- 10 tonnes of Pu currently being used in the MOX fuel manufacturing process (in the form of PuO_2, mixed oxide $(U,Pu)O_2$ and in finished MOX fuel assemblies);
- 9 tonnes of Pu in non-irradiated MOX fuel assemblies or FNR assemblies at sites other than manufacturing plants, in other words, mainly at EDF NPP sites;
- approximately 2 tonnes of Pu stored at various CEA facilities.

Of these 82 tonnes, **60 tonnes are French-owned**. Of these 60 tonnes, EDF's stock of separated Pu at La Hague comes to around 29 tonnes, i.e. 3 years' worth of MOX fuel manufacturing.

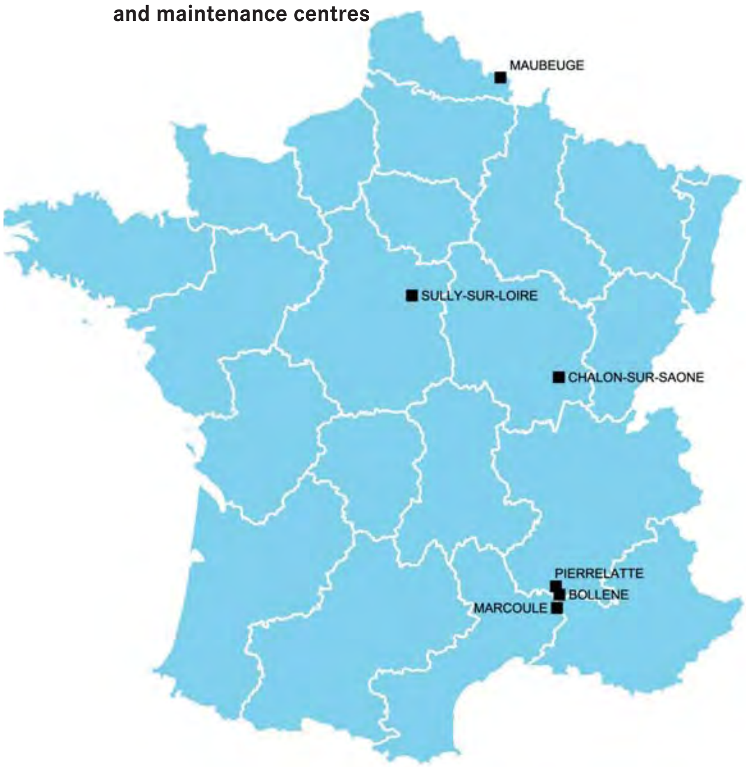
The plutonium contained in the spent fuel is not included in this count. Stocks of plutonium related to military activities (see Subchapter 4.10) is classified Defence data.

Carrousel of plutonium cans at AREVA's MOX fuel manufacturing plantat Marcoule

4.4 Waste treatment and maintenance centres

Running the various facilities that handle radioactivity entails related but required industrial support operations: treating waste arising from facility operating and maintenance. The operator usually carries out this treatment and manages any waste produced on-site. In some cases though, there are a few off-site firms that carry out such operations for one or more operators. This activity therefore applies to all economic sectors, even though the largest volumes are produced by the nuclear power sector.

Map of waste treatment and maintenance centres



Melting metal waste SOCODEI/CENTRACO

Cast ingot

4.4.1 Description of the activities and sites

Waste treatment centres

All the major centres of activity have their own listed in-house waste treatment facilities.

SOCODEI/CENTRACO at the Marcoule site (Gard) implements two processes:

- metal waste is melted;
- certain types of waste are incinerated.

It treats all the low-level solids that can be incinerated and liquid waste produced by nuclear facilities, research laboratories and hospitals. The resulting ash and clinker is rendered inert and conditioned in metal drums that go to the CSFMA disposal facility. The same applies to ingots produced by melting the metal waste.

STMI and SOCATRI in Bollène (Vaucluse) specialise in decontaminating radioactive material via conversion, conditioning and storage operations. They thus produce radioactive waste. Andra uses part of the SOCATRI facilities to store long-lived waste that cannot be accommodated in its repositories, as well as short-lived waste awaiting transfer to SOCODEI.

SOGEDEC, in Pierrelatte (Drôme), works in the area of radioactive waste treatment and is also involved in nuclear facility dismantling and cleanup, equipment and waste decontamination and maintenance for equipment used in nuclear areas.

Maintenance centres

Specialised off-site firms that provide maintenance for major facilities and/or decontaminate certain items of equipment.

The maintenance centres (Table 4.16) are small and are located at more sites than the treatment centres. They generally hold more limited quantities of waste, most of which is intended for the CSFMA disposal facility.

The B.C.O.T (Tricastin Operational Hot Unit), in Bollène, carries out maintenance operations and storage of contaminated equipment from EDF reactors, mainly reactor vessel heads, for which a replacement programme is currently in progress.

SOMANU in Maubeuge (Nord), specialises in repairing, servicing and assessing equipment, primarily from reactor coolant and auxiliary systems.

Table 4.16: Maintenance centres

B.C.O.T.	Bollène
SOMANU	Maubeuge
VISIONIC	Sully-sur-Loire
CEMO	Chalon-sur-Saône
CETIC	Chalon-sur-Saône
SOGEDEC	Pierrelatte

4.4.2 Waste produced

The waste treated and conditioned by these facilities, together with the operating waste they produce, come under this activity sector.

4.4.3 Scenario for 2008-2030

It is assumed that these facilities will continue to produce waste at a similar rate as is currently the case, i.e. approximately 800 m^3/year of LILW-SL and 200 m^3/year of VLLW.

4.4.4 General results for 2007, 2020 and 2030

Table 4.17 shows waste stocks for the "Waste treatment or maintenance centres" activity sector at the end of 2007, the end of 2020 and the end of 2030.

Table 4.17: Waste stocks at the end of 2007, the end of 2020 and the end of 2030 in m^3 conditioned equivalent

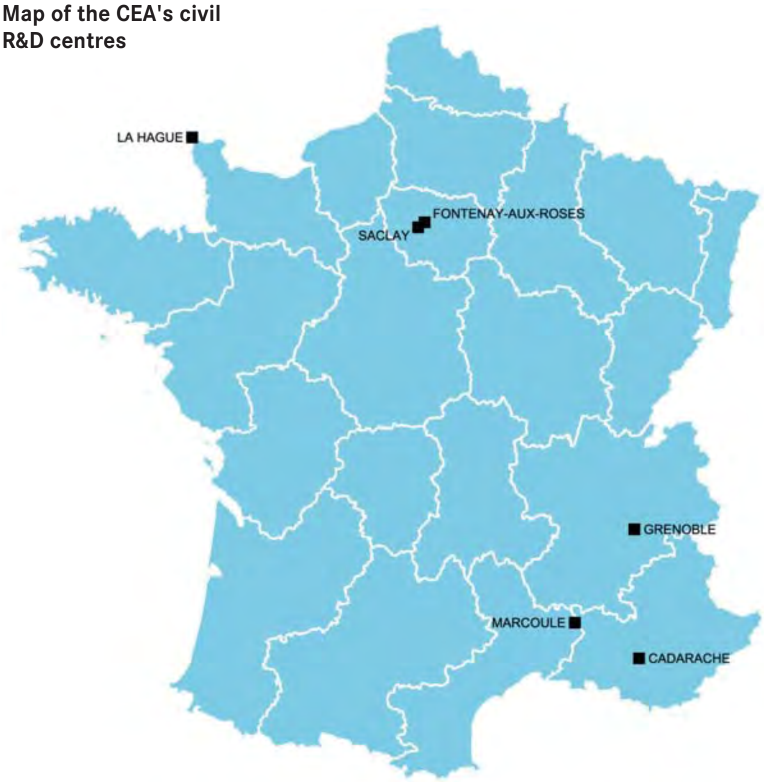
	2007	2020	2030
LILW-SL	15,308 including 13,489 already in a repository	26,093	33,161
VLLW	6,695 including 2,444 already in a repository	9,716	11,966

4.5 the CEA's civil R&D centres

This activity sector includes the French Atomic Energy Commission's (CEA) civil research centres and facilities - including ones that are currently operating and those that have been shut down. The CEA's activities relating to maintaining France's nuclear deterrent capability are described in Subchapter 4.10.

Vitrification line at Atalante (Marcoule)

Map of the CEA's civil R&D centres



4.5.1 Description of the activities and sites

Activities

The CEA provides permanent support to the nuclear industry in France, with a view to optimising existing nuclear power plants and the fuel cycle. In the back-end sector, it develops technical solutions for radioactive waste management.
At international level, the CEA is involved in research programmes on future nuclear reactors and fuels designed to ensure sustainable production that is both safer and generates less waste.

Within this framework, it is in charge of developing the prototype for a "Generation IV" reactor and, as part of a European programme, is pursuing research on controlled **thermonuclear fusion**, with the very long-term objective of generating electricity (see Box 4.2).
The CEA is responsible for cleanup and dismantling of its own nuclear facilities. Lastly, it develops programmes regarding the impact of nuclear power on health and the environment.

Sites

The CEA has **five civil research centres**, briefly described below, and four centres dedicated to military applications, described in Subchapter 4.10. It runs many facilities, laboratories and research reactors as part of its programmes. Management of its nuclear facilities produces waste similar to that of the other nuclear operators (maintenance operations waste, contaminated tools), although the waste is often more varied in nature.
It has to manage waste of the types mentioned in Subchapter 4.3 (vitrified waste and cladding waste) as a result of its research on reactor operating and spent fuel recycling.

The CEA's civil centres

Fontenay-aux-Roses

The Fontenay-aux-Roses Research Centre is undergoing major restructuring: its nuclear reseach facilities, which have been shut down, are the subject of a cleanup and dismantling programme which is now in progress. Most of the waste produced is contaminated by alpha emitters and fission products. Research areas at this historic site included chemical engineering, fuel assembly processing and the chemistry of "transuranian" elements. This is gradually being phased out, to focus more on developing research in the life sciences and technological research.

Saclay

The centre boasts major facilities (e.g. the ORPHEE and OSIRIS units) for fundamental research and applied research geared to the requirements of the nuclear power industry. The waste produced is treated and conditioned at the Centre's support facilities: INB 72 for solid waste and INB 35 for liquid waste (see Box: STELLA facility).
The pilot EL1, EL2 and EL3 reactors in the gas-cooled graphite-moderated reactor series are to be dismantled.

Grenoble

The Grenoble nuclear research centre has facilities which were used for research into the nuclear power plant sector (the MELUSINE, SILOE and SILOETTE units, all now shut down) and related support facilities.
Launched in 2001, the PASSAGE Project to clean up radioactive sites at the CEA's Centre in Grenoble involves cleanup and then dismantling of the six basic nuclear installations (INB) at the Grenoble Centre by 2012. The Centre will eventually have industrial buildings that can be used for other research activities.
The Grenoble Research Centre is now focusing primarily on new energy technologies, electronics, health and information technology.

Cleanup at the MELUSINE reactor in Grenoble

Marcoule

At the end of 2004, the Marcoule site was managed by AREVA. Responsibility for the site was transferred to the CEA at the beginning of 2005.

Activities relative to fuel-cycle back-end activities are described in Subchapter 4.3.

The Marcoule Centre also includes the PHENIX reactor, the CEA's research tool for actinide transmutation programmes, which is due to be decommissioned in the near future.

The legacy G1 reactor at Marcoule, although partly used for military purposes, has been shut down and is under the responsibility of the CEA's civil division.

Research activities include preparation techniques for uranium, developing more high-performance industrial fuel recycling processes at the ATALANTE laboratories, spent nuclear fuel processing (Act of 28 June 2006), cleanup and dismantling techniques for nuclear facilities at the end of their service life and management of the most highly radioactive waste.

PHENIX reactor at Marcoule

Cadarache

Activities at the Cadarache Centre are spread across a number of technological R&D platforms, mainly focusing on nuclear energy (fission and fusion, see Box 4.2), as well as new energy technologies and research on plant ecophysiology and microbiology.

R&D activities aim to optimise nuclear reactors and are studying uranium and plutonium-based fuel behaviour in different configurations (the now shutdown experimental FNR: RAPSODIE, or the PWR units: SCARABEE and CABRI).

The site has some twenty or so facilities including storage facilities for radioactive materials and ILW-LL.

Box 4.2

ITER: A TOOL FOR RESEARCH ON CONTROLLED THERMONUCLEAR FUSION

Aimed at developing controlled thermonuclear fusion, ITER will form a major leap forward from existing facilities to the possibility of future electricity-generating reactors based on fusion, by demonstrating the scientific feasability of this process. ITER will operate on the basis of a plasma of tritium and deuterium and will have output of 500 MW.

This fusion reactor is being developed within the framework of an international project involving the People's Republic of China, the European Union and Switzerland, Japan, South Korea, the Russian Federation and the United States of America. The partners have decided to build the reactor at the Cadarache site.

Building work should be complete within ten years. It is then expected to operate for twenty years. Dismantling the plant will be complete twenty years after the end of operating.

The waste that will be produced has been assessed as part of the project to study the "Storage of tritiated waste with no management solution", the conclusions of which were submitted to the French Ministry of Ecology, Energy, Sustainable Development and Territorial Planning (MEEDDAT) at the end of 2008 (see Box, Chapter 3). The estimated amounts are 972 m^3 of very-low-level tritiated waste, 889 m^3 of "degassing" pure tritiated waste, 12,227 m^3 of short-lived irradiating tritiated waste and 2,454 m^3 of long-lived irradiating tritiated waste.

This waste will contain high specific activity of tritium; some of it will contain beryllium.

4.5.2 Waste produced

Waste from Marcoule, related to fuel-cycle back-end activities is described in Subchapter 4.3.

HLW

There is a small volume of high-level waste, 11 m^3, which was previously conditioned by the CEA at its own facilities. This is in the form of vitrified waste at the pilot unit in Marcoule.

Other HLW has been vitrified on behalf of the CEA at the La Hague and Marcoule treatment plants. This is counted as HLW under "fuel-cycle back-end" activity (see Subchapter 4.3) and represents only a marginal proportion of this waste.

870-litre cement-embedded waste drum

Concrete package

Metal container box being filled

ILW-LL

The ILW-LL essentially comprises:
- waste in 870-litre drums, the conditioning solution adopted by the CEA, which are stored at Cadarache;
- waste in 500-litre drums or concrete packages of the same capacity;
- small volumes of waste related to specific research activities (radium-bearing lead sulphate from the CEA, etc.).

LILW-SL and VLLW

This mainly consists of the CEA's maintenance and operating waste, together with waste from dismantling decommissioned facilities. It is conditioned in metal container boxes or drums and, in the case of VLLW, in big-bags or boxes.

4.5.3 Scenario for the period 2008-2030

It is assumed that the CEA's R&D programmes will be pursued. These programmes must validate the scientific and technical options for the new generation reactors or define uranium enrichment, spent fuel recycling and waste management options.

The CEA has recently built or planned to build four new waste treatment and storage facilities:
- the radioactive liquid effluent treatment station, STELLA, in Saclay;
- the CEDRA storage facility in Cadarache;
- Advanced effluent management and treatment facility (AGATE) in Cadarache;
- the experimental Jules Horowitz Reactor (JHR), see Box 4.3.

Two of these facilities (CEDRA and STELLA, see Appendix 4 and Box 4.4) have been granted licences by interministerial decree. At the end of 2007, over 780 waste packages were stored in the CEDRA buildings.
Construction is underway on the AGATE facility (see Box 4.5) and the Jules Horowitz Reactor (see Box 4.3).

Legacy waste recovery schemes will be pursued

The CEA built up a stock of legacy waste, mostly before the 1990s. Some of this has been left in the Research facilities, while some is stored in facilities in Saclay and Cadarache. However, the conditions in which it is stored fail to meet current safety criteria.
A comprehensive plan to reocver this legacy waste has therefore been embarked upon. The resulting waste packages will be sent to the CSFMA disposal facility, or stored at CEA facilities. Recovering trenches and cells of INB 56 in Cadarache should be mentioned. These operations were part of a pilot scheme between 1995 and 1996. They are expected to produce LILW-SL and ILW-LL totalling 4,400 m^3. at current estimates.
Other legacy waste recovery operations are accounted for relative to the following installations:
- INB (Basic Nuclear Installation) 166 at the Fontenay-aux-Roses site: aproximately 150 m^3 of waste in various conditioning packages, stored in decay cells and pits and which is mainly ILW-LL, will be recovered and conditioned;
- INB 79 at the Grenoble Centre: the recovery of intermediate-level waste, mainly produced as a result of cleaning up the INBs at the CEA Grenoble Centre, is in progress. This waste recovery should be complete by the end of 2010;

- INB 22 (PEGASE) at the Cadarache site: around 2,700 100-litre drums containing contaminated waste will be treated and reconditioned on-site beginning in 2009 and will then be sent for storage at the CEDRA facility (see Appendix 4);
- INB 72 at the Saclay site: around 700 60-litre drums of compacted technological waste and miscellaneous waste will be reconditioned. Around 90% of this waste is ILW-LL.

Dismantling disused CEA facilities will continue through to 2020 and beyond. The major impetus for this is the pursuit the denuclearisation programmes at the Grenoble and Fontenay-aux-Roses Centres. Over the next two decades, the majority of VLLW will be produced as a result of these actions. When the G1 reactor is dismantled, LLW-LL graphite waste (stacks) will be produced.

The CEA's spent fuel intended for processing (i.e. all fuel other than that from the OSIRIS research reactor, GCR fuel that has not been processed to date and various experimental fuels) is taken as processed, at the La Hague plant, by 2020. Experimental reactors have produced spent fuel which must be assigned to a management solution. The CEA prefers to have it processed and recycled with a view to keeping the volume of ultimate waste to a minimum. The reference management strategy regarding spent fuel gives priority to using AREVA's processing facilities at La Hague, as such operations are subject to approval by the ASN before they can be implemented (the related waste is accounted for under Subchapter 4.3). Factors that may result in an alternative option being sought include the technical difficulties involved in processing (chemical forms of non-standard fuels) and their lack of strategic interest.
In addition, in this spent fuel production scenario, the Jules Horowitz Reactor (see Box 4.3) will be commissioned in the course of the ten-year period 2010-2020.

Note: spent fuel from the JHR is not counted under the radioactive materials described in Section 4.5.6.

Box 4.3

JULES HOROWITZ REACTOR (JHR)

The JHR is being built to develop and test new fuels and equipment that will be implemented in nuclear power plants now and in the future and, more especially, to prepare the way for 4th generation reactors. In addition to these applications in the area of power generation, the JHR will provide for 25% of Europe's demand for radionuclides used in nuclear medicine and may be used in the production of high-performance silicon for the electronics industry.

Building the JHR began on 19 March 2007. Commissioning is scheduled for 2014.

More detailed information is available online at the following address:

www.cea.fr/le_cea/actualites/reacteur_de_recherche_jules_horowitz

Fuel from the JHR will be stored on-site before being sent to AREVA's La Hague plant for processing. Ordinary solid waste (less than about a hundred m^3 per year on average, around 30% of which will be VLLW and 70% LILW-SL) will be disposed of at Andra repositories. Samples from experiments will be sent to the CEA's or other European institutes' laboratories for examination.

Production of LILW-SL related to facilities in existence at the end of 2007 is estimated to be approximately 600 m^3/year.

Box 4.4

THE RADIOACTIVE LIQUID EFFLUENT TREATMENT STATION (STELLA, IN SACLAY)

Radioactive effluent from the Paris region is treated at INB35.

STELLA, the new "process" facility (evaporation and cementation) was connected through a radioactive link to the rest of the facility in December 2008.

Active mode tests due to be carried out in 2009 form the last stage prior to the facility operating at full capacity, namely to treat 1,500 m^3 of effluent/year and cementing around 60 m^3 of evaporation concentrates.

General view of the STELLA and INB35 facilities

Box 4.5

THE ADVANCED EFFLUENT MANAGEMENT AND TREATMENT FACILITY (AGATE)

The aqueous effluent treatment station at the Cadarache site (INB37-STE), which started operating in 1965, has come to the end of its operating life.

The Advanced effluent management and treatment facility (AGATE) is the facility designed to replace INB 37 for the treatment of low- and intermediate-level effluent produced by the facilities at the Cadarache centre and other CEA centres.

The AGATE facilities are designed on the basis of:

- discharge and storage of low- and intermediate-level effluent;
- treating this effluent.

AGATE was licensed in April 2008.

The facility is to be commissioned by 2011.

4.5.4 General results for 2007, 2020 and 2030

Table 4.18 shows waste stocks for the "CEA's civil R&D centres" activity sector at the end of 2007, the end of 2020 and the end of 2030.

Table 4.18: Waste stocks at the end of 2007, the end of 2020 and the end of 2030 in m^3 conditioned equivalent

	2007	2020	2030
HLW	85	85	85
ILW-LL	10,727	11,292	11,718
LLW-LL	4	4	578
LILW-SL	112,359 including 104,322 already in a repository	128,574	135,661
VLLW	68,466 including 35,896 already in a repository	126,816	152,566

4.5.5 Waste from dismantling operations after 2030

The volumes given below refer to waste from dismantling all the CEA's facilities (including the Marcoule site).

Table 4.19: Dismantling waste after 2030 in m^3 conditioned equivalent

ILW-LL	750
LLW-LL	5,700
LILW-SL	32,000
VLLW	115,000

4.5.6 Radioactive materials

Unlike EDF's fuels, which are standard because it operates the same kind of nuclear power plants, irradiated fuel from CEA's experimental reactors comes in various forms. Spent fuel intended for recycling and, therefore, considered as radioactive material, is given in Table 4.20. Note that the spent fuel that will eventually be unloaded from the JHR is not included in this table.

Due to processing fuel from disused reactors, the CEA also possesses a stock of depleted uranium (approx. 124 tHM).

In addition, the following was also stored at CEA sites at the end of 2007: 13 tHM of uranium extracted from the mine, 14 tHM of enriched uranium and 1.5 tonnes of plutonium.

Lastly, 2,265 tonnes of thorium mainly belonging to AREVA were stored at the CEA's Cadarache site at the end of 2007.

Table 4.20: Spent fuel (in tHM) from the CEA's civil activities pending processing at the end of 2007, the end of 2020 and the end of 2030

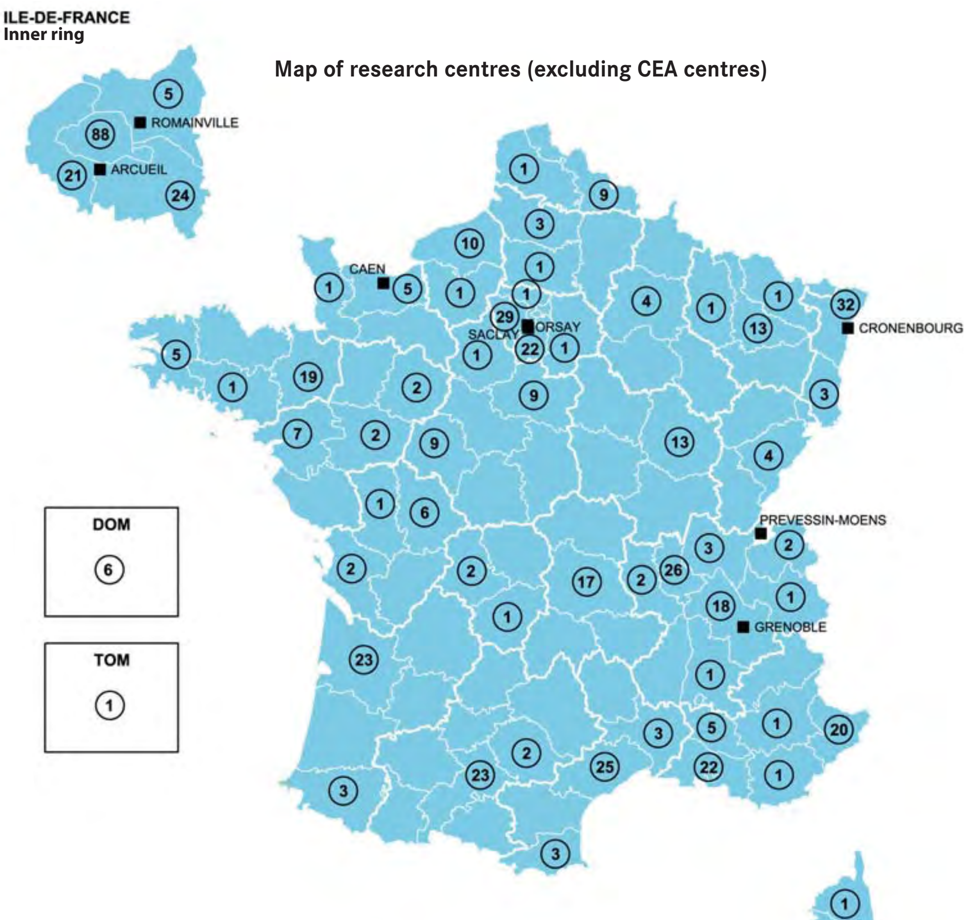
Fuel	2007	2020	2030
FNR (PHENIX)	40	3	0
Miscellaneous	1	1	0

4.6 research centres (excluding the CEA)

This activity sector covers all public or private research centres, together with the units of all the major organisations or industrial groups that are mainly or exclusively involved in Research.

Aerial view of the GANIL. The major national heavy ion accelerator (GANIL) in operation since 1983, is a facility shared by the DSM (CEA) and IN2P3 (CNRS)

Map of research centres (excluding CEA centres)



○ Number of centres counted in French *départements*

■ Centre listed in the Geographical Inventory

4.6.1 Description of the activities and sites

Many public and private organisations use radionuclides. Altogether, Andra has listed 569 producers in the Research sector (excluding the CEA) at the end of 2007. These include:

- the many medical research laboratories attached to faculties of Medicine or Pharmacology, or based at hospitals or university teaching hospitals;

- CNRS laboratories or laboratories belonging to joint research units associated with the CNRS, usually located within faculties, institutes or Grandes Ecoles;
- units of the French National Institute of Nuclear Physics and Particle Physics (IN2P3), including the particle accelerators at Orsay and Caen (GANIL);
- the reactor belonging to the Laue Langevin Institute (ILL) in Grenoble and the European Centre for Nuclear Research (CERN), on the border between France and Switzerland;
- centres, laboratories and units associated with the French National Institute for Agricultural Research (INRA);
- the French Blood Establishment (EFS), which carries out medical biology tests and analyses;
- INSERM research units, mainly located in hospitals, university teaching hospitals and cancer centres;

Handling in the laboratory

- private-sector research centres and units in the chemical and pharmaceuticals industries;
- various decommissioned reactors and facilities (including the ULP reactor in Strasbourg).

4.6.2 Waste produced

In this sector, the most commonly-found very-short-lived radionuclides are phosphorus-32 and 33, sulphur-35, chromium-51 and iodine-125; short-lived radionuclides are tritium and long-lived radionuclides carbon-14. In cellular and molecular biology, these are used to mark the molecules into which they are incorporated. They are often used in the form of unsealed sources (that is, small liquid samples). After use, they become liquid waste, which is generally entrusted to Andra to be forwarded to CENTRACO for treatment (see Subchapter 4.4). If this waste has a half-life of less than 100 days, it is left *in situ* to allow it to decay.

Most of the waste is LILW-SL or VLLW

It is produced by research facilities that have particle accelerators: the residue of products used (tritium, alpha emitters) or equipment activated by particle flux. The use of unsealed sources also leads to the production of contaminated solid waste (gloves, tubes, glassware, etc.). Sealed sources are also used (see Subchapter 4.8).

Table 4.21 shows the radionuclides listed in the Research sector.

Table 4.21: Radionuclides used most widely in the research sector (based on producers' declarations)

Radio-nuclide	Name	Radioactive half-life	Radio-nuclide	Name	Radioactive half-life
^{3}H	TRITIUM	12.33 years	^{103}Ru	RUTHENIUM-103	39.26 days
^{7}Be	BERYLLIUM 7	53.20 days	^{109}Cd	CADMIUM-109	1.27 years
^{14}C	CARBON-14	5,700 years	^{111}In	INDIUM-111	2.80 days
^{22}Na	SODIUM-22	2.6 years	^{123}I	IODINE-123	13.22 hours
^{32}P	PHOSPHORUS-32	14.27 days	^{125}I	IODINE-125	59.41 days
^{33}P	PHOSPHORUS-33	25.38 days	^{126}Sn	TIN-126	$2.3x10^{5}$ years
^{35}S	SULPHUR-35	87.32 days	^{129}I	IODINE-129	$1.61x10^{7}$ years
^{44}Ti	TITANIUM-44	60 years	^{131}I	IODINE-131	8.02 days
^{45}Ca	CALCIUM-45	163 days	^{133}Ba	BARIUM-133	10.5 years
^{46}Sc	SCANDIUM-46	83.81 days	^{134}Cs	CAESIUM-134	2.07 years
^{51}Cr	CHROMIUM-51	27.7 days	^{137}Cs	CAESIUM-137	30.04 years
^{53}Mn	MANGANESE-53	$3.68x10^{6}$ years	^{139}Ce	CERIUM-139	137.64 days
^{54}Mn	MANGANESE-54	312.1 days	^{141}Ce	CERIUM-141	32.50 days
^{56}Co	COBALT-56	77.31 days	^{152}Eu	EUROPIUM-152	13.53 years
^{57}Co	COBALT-57	271.8 days	^{153}Gd	GADOLINIUM-153	240.4 days
^{59}Fe	IRON-59	44.5 days	^{154}Eu	EUROPIUM-154	8.6 years
^{60}Co	COBALT-60	5.27 years	^{169}Yb	YTTERBIUM-169	32.01 days
^{65}Zn	ZINC-65	244.15 days	^{185}W	TUNGSTEN-185	75.1 days
^{68}Ga	GALLIUM-68	1.13 hours	^{194}Hg	MERCURY-194	440 years
^{75}Se	SELENIUM-75	119.64 days	^{204}Tl	THALLIUM-204	3.8 years
^{83}Rb	RUBIDIUM-83	86.2 days	^{207}Bi	BISMUTH-207	37.76 years
^{85}Sr	STRONTIUM-85	64.85 days	^{208}Po	POLONIUM-208	2.93 years
^{86}Rb	RUBIDIUM-86	18.64 days	^{210}Pb	LEAD-210	22.2 years
^{88}Y	YTTRIUM-88	160.63 days	^{226}Ra	RADIUM-226	1,600 years
^{88}Zr	ZIRCONIUM-88	83.4 days	^{227}Ac	ACTINIUM-227	21.77 years
^{90}Sr	STRONTIUM-90	28.8 years	^{231}Pa	PROTACTINIUM-231	$3.28x10^{4}$ years
^{95}Nb	NOBIUM-95	35 days	^{232}U	URANIUM-232	69.8 years
^{99}Tc	TECHNETIUM-99	$2.14x10^{5}$ years	^{233}U	URANIUM-233	$1.59x10^{5}$ years

Source: JEF 3.1.1. decay data library (OECD-NEA)

4.6.3 Scenario for 2008-2030

In this activity sector, the current waste production level is expected to be stable at around 100 m³ per year of LILW-SL and 400 m³ of VLLW.
This overall forecast also includes waste from medical establishments (see Subchapter 4.7).

4.6.4 General results for 2007, 2020 and 2030

In the course of 2007, Andra collected approximately 310 m³ of waste from private research, public research and hospitals. The proportion of this waste that has been disposed of in the CSFMA disposal facility is mainly compacted or incinerated waste.
Table 4.22 shows waste stocks for "Research Centres (excluding the CEA)" activity sector at the end of 2007, the end of 2020 and the end of 2030.

Table 4.22: Waste stocks at the end of 2007, the end of 2020 and the end of 2030 in m³ conditioned equivalent

	2007	2020	2030
ILW-LL	2	2	2
LLW-LL	63	63	63
LILW-SL	13,165 including 12,313 in a repository	15,178	16,677
VLLW	2,160 including 796 in a repository	7,360	11,360

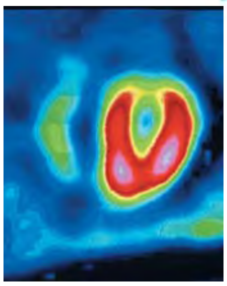
Medical activities: diagnosis, therapy, and analysis

4.7

This activity sector includes all the public and private establishments that use radionuclides for medical analysis or treatment. Medical research centres are not included as they belong under the preceding activity sector.

Map of medical sector centres

Sealed source – cobalt-60 gamma beam therapy



Cardiac scan

Box of radium needles

Handling in the laboratory

4.7.1 Description of the activity and sites

This sector covers three major areas:

- *in vitro* **biological** analyses carried out on biological samples for the purposes of diagnosis;
- **medical imaging** techniques, used in diagnosis;
- **therapeutic** applications, carried out *in vitro* or *in vivo*.

The 264 sites are the following:

- **public and general hospitals**, if they have a nuclear medicine department (medical and/or therapeutic imaging) and/or biological laboratories;
- **private clinics and hospitals** with their own internal units (diagnosis or therapy) or that accommodate external units (radiotherapy units);
- **university teaching hospitals (CHU)**
  These group together one or more hospitals and have biology or biochemistry departments. They often accommodate external units (the INSERM and medicine or pharmacology faculty laboratories, etc.);
- **clinical laboratories,** specialising in biological analyses;
- **regional cancer centres (CRLCC)**
  These private sector, non-profit-making centres have nuclear medicine units, clinical laboratories and biomedical research units;
- **French Armed Forces Health Services (SSA)** with their military teaching hospitals (HIA) and specialised laboratories (tropical medicine, etc.).

These establishments mainly use **unsealed sources**, i.e. radioactive elements in liquid solution. The main users of these sources are nuclear medicine departments and their associated laboratories, as well as biomedial research laboratories.

The same establishments also use sealed sources (see Subchapter 4.8) for radiotherapy, brachytherapy and calibrating the instruments used to measure the activity of the injected products. Thses sources are also used to check cameras sensitive to hospital scanner rays and cameras used for positron emission tomography.

Applications

Applications in *in vitro* diagnosis

Carried out at radiography laboratories, which are usually linked to nuclear medicine departments, and used to make bioassays on samples.

Radiography analyses are essential when conventional assay techniques fail, for example, if the content of the substance being assayed is low or because of its chemical complexity. The main radionuclides used are tritium, phosphorus-32 and iodine-125, among others.

Many of the listed laboratories also carry out radio-immuno-assays. Some chemiluminescence-based techniques are beginning to replace the use of radionuclides, for example for hormone assays.

Applications in *in vivo* diagnosis

Various diagnosis applications using medical imaging are based directly on the properties of radioactivity: X-rays or radionuclides. These techniques are used to locate and examine body organs (anatomical medical imaging), or visualise how they are working (functional medical imaging).

In isotope scanning, when a radiopharmaceutical is administered to the patient, a detecting device tracks the marker in the body to create a dynamic internal image of an organ, for example.

It works out how the organ functions by interpreting the images obtained and provides what is known as an *in vivo* diagnosis.

Radionuclides are still widely used for bone, thyroid, cardiac and lung scans, etc.

The most commonly-used radionuclides are metastable technetium-99, thallium-201, iodine-131, iodine-123 and gallium-67 (see Table 4.23).

Tomography techniques draw on the properties of X-rays or gamma rays. Developments are set to extend fluorine-18 positron emission tomography applications to the fields of neurology, cardiology and oncology.

Table 4.23: Main radionuclides used in the medical sector (classified in ascending order according to mass number) together with radioactive half-life

Radio-nuclides	Name	Radioactive half-life
^{3}H	TRITIUM	12.33 years
^{14}C	CARBON-14	5,700 years
^{15}O	OXYGEN-15	2.04 minutes
^{18}F	FLUORINE-18	1.83 hours
^{22}Na	SODIUM-22	2.6 years
^{32}P	PHOSPHORUS-32	14.27 days
^{33}P	PHOSPHORUS-33	25.38 days
^{35}S	SULPHUR-35	87.32 days
^{51}Cr	CHROMIUM-51	27.7 days
^{57}Co	COBALT-57	271.8 days
^{58}Co	COBALT-58	70.86 days
^{67}Ga	GALLIUM-67	3.26 days
^{68}Ga	GALLIUM-68	1.13 hours
^{68}Ge	GERMANIUM-68	270.95 days
$^{81(m)}$Kr	KRYPTON-81$^{(m)}$	12.8 seconds
^{81}Rb	RUBIDIUM-81	4.58 hours
^{88}Y	YTTRIUM-88	106.63 days
^{89}Sr	STRONTIUM-89	50.57 days
^{90}Y	YTTRIUM-90	2.67 days
^{99}Mo	MOLYBDENUM-99	2.75 days
$^{99(m)}$Kr	TECHNETIUM-99$^{(m)}$	6.01 hours
^{111}In	INDIUM-111	2.80 days
^{123}I	IODINE-123	13.22 hours
^{125}I	IODINE-125	59.41 days
^{131}I	IODINE-131	8.02 days
^{133}Xe	XENON-133	5.24 days
^{137}Cs	CAESIUM-137	30.04 years
^{153}Sm	SAMARIUM-153	1.93 days
^{169}Er	ERBIUM-169	9.40 days
^{186}Re	RHENIUM-186	3.78 days
$^{186(m)}$Re	RHENIUM-186$^{(m)}$	1.996×10^{9} years
^{192}H	IRIDIUM-192	73.82 days
^{201}Tl	THALLIUM-201	3.04 days
^{226}Ra	RADIUM-226	1,600 years
^{227}Ac	ACTINIUM-227	21.77 years

Source: JEF 3.1.1. decay data library (OECD-NEA)

Therapy applications using unsealed sources are based on selective cell destruction, through the use of radiopharmaceuticals containing a radionucleide that fixes itself lastingly and specifically to the organ or tissue to be irradiated. The aim, as in external radiotherapy, is to destroy the cancer cells and preserve the maximum number of healthy cells. Some techniques demand specific radionuclides conditioned in particular ways (iodine-131 in capsules, iridium-192 in wires)

Medicine also uses sealed sources For example, radiotherapy relies on gamma-rays from cobalt-60 sources. Caesium-137 is no longer used in external radiotherapy and cobalt-60 is gradually being withdrawn from use. Sealed sources used in radiotherapy have high activity levels, with half-lives that last several years. The number of licences for gamma beam therapy is much higher than the number of units that have equipment containing sources. Now that the technique is obsolete, this equipment has been replaced by accelerators.

In brachytherapy (or internal radiotherapy), certain forms of cancer, such as prostate cancer, are treated by means of a permanent iodine-125 seed implant in the prostate and, in gynaecology, by the internal application of a caesium-137 seed implant, in a sealed tube. The main radionuclides used in brachytherapy, caesium-137, iodine-125 and iridium-192 have now permanently replaced radium, which was conventionally used in the first half of the 20th century in the form of needles and tubes. Their radioactive half-lives are 30 years, 59.4 days and 73.8 days respectively.

Radium-bearing items

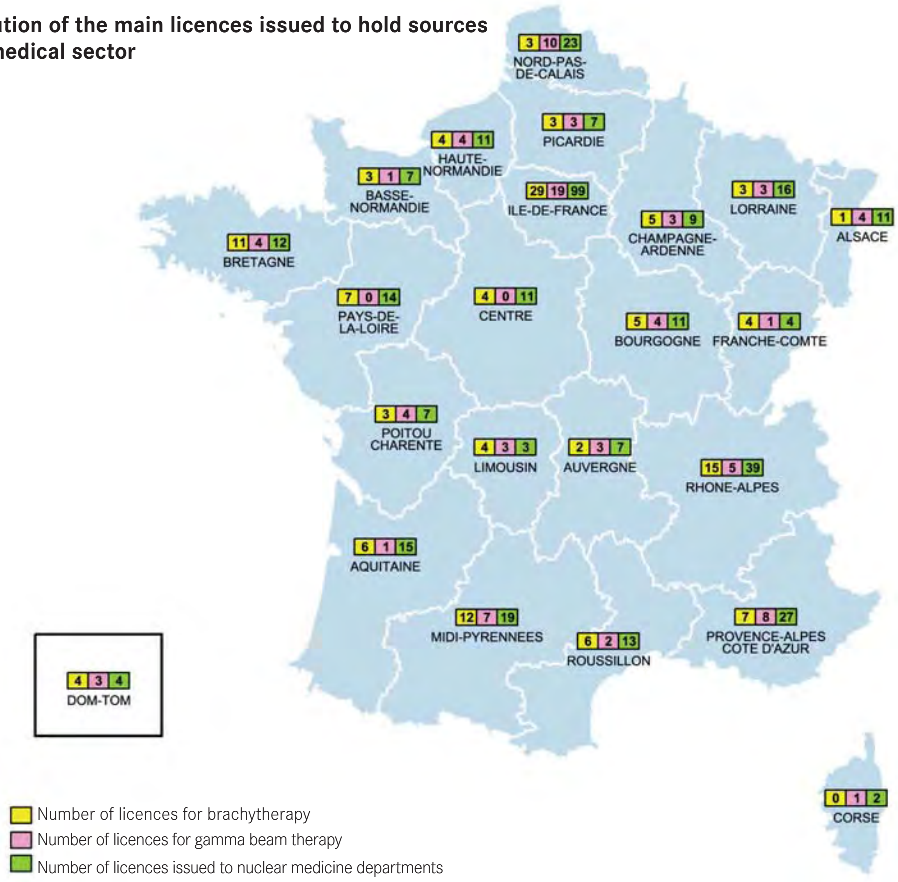
The manufacture, production and sale of radium-bearing items were banned at the end of the 1950s due to the radioactive radiation hazards involved. Up to that time, radium was used for many applications, some of which we would now find surprising. The majority of items to be potentially collected are radium-bearing medical devices (needles and applicators used to treat tumours).

In 1985, the Central Service for Protection against Ionising Radiation (S.C.P.R.I), followed by the Office for Protection against Ionising Radiation (O.P.R.I) and Andra in 1999 and 2000, recovered over 3,400 items amounting to about 1.3 TBq of radium from radiology units, clinics and cancer centres and, in particular, from private individuals. Some 2,800 radium-bearing medical items were collected during the first wave, a further 500 in the second wave, and a few dozen items since then.

Licences to hold radioactive sources

As at 31 August, there were 680 valid licences to hold sealed or unsealed sources issued within the medical sector (see map on next page). It should be noted that a single establishment can be issued with more than one licence and that a single licence may cover several sources of the same kind (the 680 licences issued thus cover 4,700 sources).

Distribution of the main licences issued to hold sources in the medical sector



Note:

In all, 35,369 sources were registered as being held by users in 2008 (this increase is linked to the fact that the figures now include sources affected by changes in the regulations in 2002 and an increase in the number of sources used for lead detection in building surveys).

4.7.2 Waste produced

The use of unsealed sources of radioelements in nuclear medicine produces radioactive waste and effluent. The solid waste consists of the empty bottles that have been used to hold radioactive liquids and small items of laboratory equipment (tubes, glassware, gloves, syringes, needles, soiled cotton wool).

The liquid effluent comes from the various preparations (equipment rinsing water, scintillator materials used for counting certain radioelements, etc.).

Sealed sources used in radiotherapy, which are highly radioactive and have half-lives lasting several years, are returned to the suppliers after use.

At units that produce waste, solid waste is stored in special containers to prevent any radioactive, infectious and/or chemical risk. Very-short-lived waste is stored separately *in situ* pending the decay of its radioactivity and then removal. It is then removed by conventional hospital waste disposal firms once final measurements have been made of any residual radioactivity. There is only a very small volume of waste that cannot be handled in this way and needs to be sent to an Andra repository. This is accounted for in the Inventory along with the waste produced by "small-scale nuclear activities" waste producers in the Research sector (see preceding Subchapter). Aqueous effluent, from laboratoires and the washrooms of hospital rooms reserved for patients treated with doses of iodine-131, is collected in tanks and stored on-site to allow for decay.

Marked non-aqueous effluent (scintillation liquid) is kept separate and removed by Andra, which sends it to the CENTRACO incinerator (see Subchapter 4.4).

4.7.3 Scenario for 2008-2030

Medicine uses unsealed sources similar to those used by research centres (cf. Subchapter 4.6) as well as sealed sources, which are managed by the manufacturers. Waste produced by this activity is therefore described under the relevant subchapters. The scenario adopted assumes that current practices will continue.

Note:

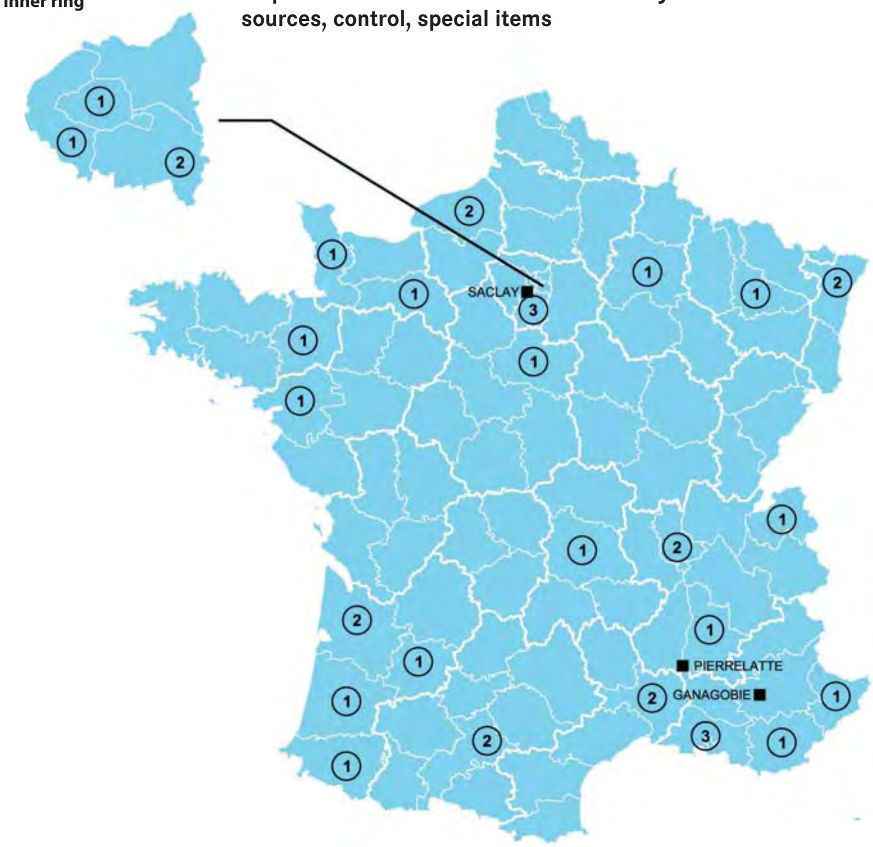
Stocks of radium-bearing items for medical use are assumed to be stable. This is because the number of requests for collection has remained stable and low for several years compared with the total stock.

miscellaneous industrial activities:
manufacturing sources, control, special items

4.8

These activities encompass the manufacture and industrial use of radioactive sources (sealed and unsealed) outside the medical sector, which has been covered in the subchapters above. They also include the manufacture and use of miscellaneous devices that use radioactive products (lightning rods, smoke detectors, etc.) or the properties of radioactivity (monitoring sources for compliance, maintenance, etc.).

Map of "miscellaneous" industrial activity sites: manufacturing sources, control, special items



Smoke detector

Storing spent sealed sources

Sealed sources, mainly related to measuring equipment, do not entail any risk of radioactive dispersal when used under normal conditions. Radiation exposure is therefore the only risk that they may pose. Above a certain activity threshold, a licence, issued by the administrative authorities, is required for their distribution, allowing the holder to manage them independently until they are returned to the distributor, and then to the manufacturer.

In contrast, unsealed radioactive sources are directly integrated into the material. These present both the risk of radiation exposure (this goes for all sources) and that of contamination by contact, ingestion or inhalation. Mainly used to mark molecules and as radioactive tracers (see Subchapters 4.6 and 4.7), they are used when and as needed and are not generally recovered. Possession and use of unsealed sources above a certain radioactivity threshold also requires an administrative licence.
The activities described in this subchapter mainly involved the use of sealed sources.

4.8.1 Description of the activities and sites

Source manufacturing and use

The use of artificial radioelements for "non-destructive tests",
in other words, to characterise materials without affecting their integrity, is common practice in industry. This includes applications in:

gamma radiography test to check welds for flaws, which is a genuine radiographic examination of metal (iridium-192 or cobalt-60 sources);

measurement of the density, level or thickness of materials such as paper, fabric, plastic or thin metal using gauges made up of a krypton-85, caesium-137, americium-241, cobalt-60 or promethium-147 emitter unit and a radiation detector unit;

detecting molecules and their assay for products such as pesticides, explosives or drugs by analysing gaseous-phase chromatographs using nickel-63 or tritium sources. Cadmium-109 and cobalt-57 are also used to detect toxins, such as lead in paint;

controlling EDF nuclear power reactors. Controlling and monitoring the operation of nuclear power reactors requires the use of sealed sources in:

- **radiological protection systems** using sources of caesium-137, strontium-90, radium-226 and americium-241, all of which have activity levels below 3.7 MBq;
- **capacity measuring systems** using americium-beryllium sources whose activity levels are below 150 GBq;

industrial irradiation
This makes use of the biological effects of radiation on living matter to:

- **sterilise medical equipment and pharmaceuticals;**
- **preserve certain foodstuffs** by destroying any micro-organisms and parasites they harbour;
- **inhibit germination** (e.g. of potatoes) using low dose irradiation;
- **disinfest cereals and fruit;**
- **slow down physiological decomposition processes using** low dose irradiation;
- **extend food preservation times** using mean dose irradiation
- **sterilise meat, spices and prepared foodstuffs for industry,** using high dose irradiation.

In France, there are several industrial irradiators that use high level (800 TBq) sealed sources (cobalt-60 or caesium-137). Given the activity levels involved, these facilities are classified as Basic Nuclear Installations (INB).
The sale of sealed sources used in these industrial applications is a competitive market. As at 31 December 2007, 196 licences to distribute sealed and unsealed sources for industrial use had been issued by the authorities with jurisdiction in the matter (some distributors may hold industrial and medical licences). These include around twenty foreign distributors based within the European Union.
Returning used sealed sources to the supplier and then to the manufacturer is a regulatory requirement with which the user undertakes to comply at the time of purchase.
Most of the major distributors of sealed sources are members of a professional association set up to guarantee that, in the event that any one of the members should default, a solution to recover any spent source will be sought and the costs incurred covered.
As at 31 August 2008, nearly 6,178 licences to hold sealed or unsealed sources had been issued within the industrial sector (see map opposite), including around 5,750 for sealed sources (more than one licence can be issued to a single organisation, and a single licence may cover a number of sources regardless of whether or not they are of the same nature).
In mid-2008, licences to hold radioactive sources in the industrial sector referred to nearly 26,000 sources (with initial activity above the exemption level).

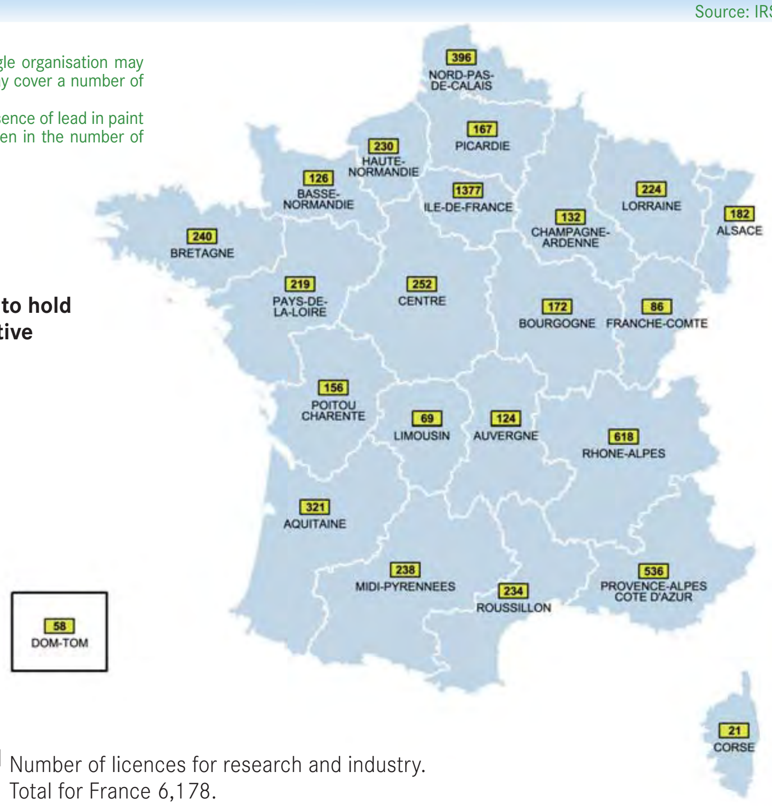
Table 4.2: Main uses of sealed radioactive sources

	Number of licences registered mid-2008*
Gammagraphy	163
Irradiation	73
Measuring density and weight	360
Measuring thickness	188
Measuring dustiness	75
Measuring the thickness of thin films	21
Measuring basis weight	228
Measuring levels	382
Measuring humidity and density	270
Logging	11
Removing static electricity	32
Smoke detectors	3
Installing neutron sources	43
Analysis	99
Calibration	1,001
Education	140
Research	25
Chromatography	462
Electron capture detector	59
X-ray fluorescence analysis**	3,039

Source: IRSN 2008

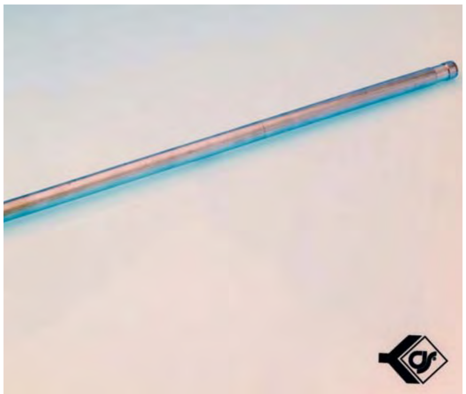
* This refers to licences, not to organisations. A single organisation may have more than one licence and the same licence may cover a number of different uses.
** X-ray fluorescence analysis devices detect the presence of lead in paint (lead-poisoning prevention). A marked rise can be seen in the number of licences registered in this sector.

Geographical distribution of licences to hold and use sealed and unsealed radioactive sources (research and industry)

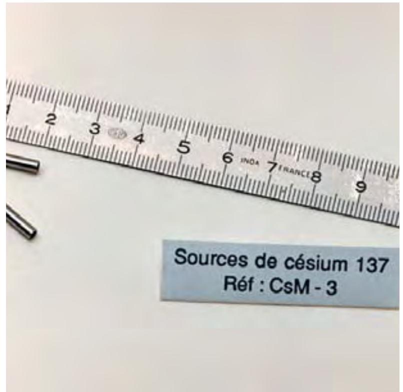


Number of licences for research and industry.
Total for France 6,178.

A single organisation may hold several licences (source: IRSN 2008)



Sources for industrial irradiators



Sources for gammagraphy

In addition, there are a further 434 licences relative to holding electrical ionising radiation devices (primarily X-ray generators) that do not contain radioactive sources.

Inventory and monitoring of sealed sources

There is a special monitoring system for tracking the movements of all sealed sources distributed.

Since 1952 (the year in which the CIREA, France's Interministerial Commission for Artificial Radioelements was set up), any person that wishes to hold, use or sell radioactive sources must be granted authorisation by the government. The French Institute for Radiological Protection and Nuclear Safety (IRSN) records the movements of these sources in France and keeps its own inventory on them up to date. This enables any source to be located, gives information on its radioelement, its radioactivity on a given date, the date the licence was granted to use it, the name of the user organisation and the technique for which it is used. It is thus possible to know the number and use of every sealed source at any time.

However rigourous it may be, this Inventory does not include artificial radioelements below a certain activity level, provided that the user does not require authorisation to hold the radioactive sources in question (Article R.1333-45 of France's Public Health Code).

Since Decree 2002-460 of 4 April 2002, sources containing natural radioelements, including radium and thorium, have been subject to the ordinary rules of law.

The National Inventory is unable to account for unidentified and unlisted sources (which are often small sources used for gauging or calibrating measuring instruments).

Major manufacturers and storage sites in France

The Radioactivity Standards Laboratory (CERCA LEA)

This is the only sealed source manufacturer in France and is located at the Pierrelatte site.

It is owned by AREVA and SIEMENS and has held a monopoly in the market since Cis-Bio International stopped production at Saclay. The CERCA LEA produces around 4,000 sources a year, all types combined.

The commodities needed to manufacture calibration sources are high activity solutions or solid or gaseous products, produced in reactors or particle accelerators.

Cis-Bio International

Cis-Bio International, now a Schering SA subsidiary, has the Poséidon irradiator, which contains irradiation devices for biomedical and industrial products. The firm has refocused on radionuclide substitutes for diagnostic and therapeutic applications and for the pharmaceutical industry. It continues to supply short-lived "radiopharmaceuticals" (molecules marked by a radioelement). Cis-Bio International stores spent sealed sources at the Saclay site for itself and on behalf of the CEA.

The CEA's INB 72 at the Saclay site

This facility houses about 155,000 sources of all types from the recovery of sealed sources recovered by the CEA through its obligation as supplier to retrieve them or as part of a public service offered for orphan sources as requisitioned by the public authorities.

Special cases of items in the same category as spent sealed sources

Lightning rods

The manufacture of lightning rods with radioactive "heads" ceased in 1983 and they have been banned from sale since 1987. The heads may, depending on the model, contain 3 to 75 MBq of radium-226, or 22 to 33 MBq of americium-241.

An estimated 50,000 radioactive lightning rods are believed to have been sold in France. There is no obligation to remove them. However, every time one is dismantled, it must be removed and managed as radioactive waste. These lightning rod heads are stored together by professional firms. Andra issues a (non-exhaustive) list of such firms to anyone owning a lightning rod (see Table 4.25). It should be noted that collecting and storing radioactive lightning rods is subject to licensing by the French Nuclear Safety Authority (ASN). The majority of these firms should be so authorised by the end of 2009.

Andra collects around 500 to 600 of these heads every year and places them in storage pending a suitable disposal solution.

Given their radioactivity, lightning rods containing radium-226 are sent to the CEA's Cadarache Centre to be compacted and conditioned in 870-litre drums pending a suitable management solution.

Lightning rods bearing americium-241 are conditioned and stored on a special platform at the SOCATRI site in Bollene (84), which Andra has been authorised to use since August 2003. These lightning rods are placed in 200-litre drums.

Andra has recovered just over 7,700 lightning rod heads all told, two-thirds of which contain radium-226 while the remaining third contains americium-241.

Radium-tipped lightning rod

Smoke detectors

The most widely-used model makes use of the radioactive properties of small americium-241 sources. The source ionises the air contained in the device. When smoke enters it, electrical conductivity drops, thus setting off the alarm. It is hard to estimate the stock, which is somewhere between 6 and 8 million installed units, amounting to a few hundred GBq of radioactivity in all.

Table 4.25: List of firms involved in collecting lightning rods

Département	**Site (Organisation)**
Gironde	EYSINES (INDELEC)
Ille-et-Vilaine	RENNES (INDELEC)
Nord	DOUAI (INDELEC)
Bas-Rhin	MUNDOLSHEIM (PROTIBAT)
Bas-Rhin	STRASBOURG (SAP)
Rhône	MORNANT (INDELEC SUD-EST)
Haute-Savoie	ANNECY (S.A.E. Société Annecienne Équipement)
Seine-et-Marne	OZOIR-LA-FERRIÈRE (FRANKLIN France)
Val-de-Marne	CHENNEVIÈRES/Marne (DUVAL MESSIEN)
Val-d'Oise	PERSAN (ABB HELITA)

Source: Andra (2008)

The activity of these sources is very low (4 kBq for the latest models) and is regulated. These detectors are prohibited for domestic use but are often used in office blocks and public buildings. The public authorities are examining banning their use.

Radioluminescent plates bearing radium-226 and tritium

Paint containing radium was used up until the 1960s for night vision applications (compasses, signalling, luminous watch dials and hands, alarm clocks and clocks, etc.). These items are no longer manufactured.

Radium has partly been replaced by tritium, a radioelement with a shorter half-life and which is much less toxic, but which is now largely being replaced by photoluminescent paint (which is not radioactive), where its properties permit.

Other radium-bearing items

In addition to items for medical use, covered in Subchapter 4.7, the use of radium for "fancy" items led to the manufacture of miscellaneous items (radium fountains, spark plugs, etc.) until the end of the 1930s. These are gradually being collected and stored by the CEA.

Other industrial activities that come under this category

In addition to the activities described above, the National Inventory includes those industries that use the properties of radioactivity, often artificial, in this category.

For example:
- radiopharmaceutical manufacturers (Cyclopharma,etc.);
- pharmaceutical reagent manufacturers (Immunotech, Ipsen Pharma Biotech, Diasorin, etc.);
- maintenance, source compliance monitoring and equipment decontamination firms (CETIC, CERAP, Intercontrôle, Saphymo, SGS Multilab, Elta, etc.);
- transit zones for foreign manufacturers' sources (Healthcare, formerly Amersham, for example).

4.8.2 Waste produced

Sources at the end of service life

Depending on the half-life of the radioelement in question, their limited service life makes these sources unusable after a few months or years. They are not automatically considered as ultimate waste.

Until recently, Decree 2002-460 of 4 April 2002 required users of obsolete or spent sealed sources collected within a maximum period of ten years, unless they received dispensation from the ASN.

Now, Article R.1333-52 of the French Public Health Code, introduced by Decree 2007-1582 of 7 November 2007, specifies that, by special dispensation, this obligation is not applicable if the characteristics of a source allow for its decay at the site where it has been used (mainly in the case of low-level activity and short half-life).

Further, Article R.4452-12 of the French Labour Code requires that all sources used be subject to regular technical radiological protection inspections.

Many sources are returned to their suppliers abroad. Others are stored at suitable premises. Some may be disposed of at the CSFMA disposal facility provided that they meet the facility's safety requirements. A first batch of 995 units, with sufficiently low-level activity and a half-life of less than 5 years, has been accepted under this scheme.

The regulatory requirement to return sealed sources sometimes causes problems: some suppliers and manufacturers may go out of business or fail to fulfil their recovery obligation. Interim storage solutions are then found for these orphan sources at the CEA.

Source manufacturing waste

Most of the waste produced by manufacturing at the Radioactivity Standards Laboratory (CERCA LEA) is dealt with via existing management channels. This is waste from the facility's production lines, contaminated by using very high activity stock solutions, and by transferring or incorporating them into a variety of inert materials. (see Tables 4.26 and 4.27)

Table 4.26: Waste produced by CERCA LEA's source manufacturing in 2007

	Type	Annual output	Management solution
Solids	Glassware Lead Resin	60 kg 60 kg 20 kg	LILW disposal facility (CSFMA)
Combustible solids	Plastic paper Metal Glassware	350 kg 4 kg 1.5 kg	LILW disposal facility (CSFMA)
Liquids	Washwater Active solution Scintillation liquid Organic liquid Used oil Contaminated acetone	2,000 litres 5 litres 6 litres 1 litre 2 litres 1 litre	LILW disposal facility (CSFMA)
Metal (related to maintenance)	Metal	100 kg	Melting, then to LILW disposal facility (CSFMA)

Source: CERCA LEA 2008

Table 4.27: Waste produced by noncompliant or obsolete sources at the CERCA LEA in 2007

Type of waste	Quantity (in kg)	Management solution
Resins and plastic	510	Incineration then to LILW disposal facility (CSFMA)
Stainless steel and platinum disk	100	Melting, then to LILW disposal facility (CSFMA)
Glass and resin	15	LILW disposal facility (CSFMA)
Duralinox rings (residue from disbonding sources)	150	LILW disposal facility (CSFMA)
Resins and monazite	50	LILW disposal facility (CSFMA)

Source: CERCA LEA 2008

4.8.3 Scenario for the period 2008-2030

The scenario adopted assumes that the French market in sources for industrial use will decline. More specifically:

"EDF predicts that around 15,000 sources in all categories have been or will be used during the operating life of its industrial sites up to 2030. The activity level will be around 24 TBq."

The number of sources produced and sold by the **CEA** to meet demand by users other than at its own centres, and which it is required to recover, is estimated at less than 100,000.

Cis-Bio plans to recover its sources up to 2018, peaking around 2010/2012. To this end, a public interest group has recently been formed by the CEA and Cis-Bio as part of the programme to recover spent sources still in circulation. Their aim is to collect these sources within a period of 10 years. Production at **CERCA LEA** is set to grow steadily, especially through developing exports. CERCA LEA has equipment to dismantle its sealed sources recovered at the end of their service life, such that it can optimise disposal management flows to Andra or carry out partial, or even total, recycling whenever possible.

Production of americium-bearing smoke detectors is diminishing. There are other technical solutions that do not rely on radioactivity (optical smoke detectors). Moreover, the radioactivity of current detectors is lower than in the past. The GESI, the syndicate for the sector, is planning to gradually reduce stocks over the next ten years or so.
On the basis of this, a total of 6 to 8 million units would be recovered for treatment prior to long-term management (i.e. the equivalent of the current installed base, counting the return of used detectors to their foreign manufacturers).

Andra will continue to collect lightning rods at the rate of 500 to 600 heads per year. Two-thirds of this annual flow contains radium and the remaining third contains americium.

4.8.4 General results for 2007, 2020 and 2030

Table 4.28 shows waste stocks for the "Miscellaneous industrial activities" sector at the end of 2007, the end of 2020 and the end of 2030.

Table 4.28: Waste stocks at the end of 2007, the end of 2020 and the end of 2030 in m^3 conditioned equivalent

	2007	2020	2030
ILW-LL	126	126	126
LLW-LL	121	245	245
LILW-SL	1 including 1 already disposed of	1	1
VLLW	287 including 244 already in a repository	2,237	3,737

Of the total 126 m^3 of ILW-LL, there are 125 m^3 of old source packages with characteristics that made them unsuitable for disposal at the CSM disposal facility (Manche), and 1 m^3 of operating waste from Cis-Bio International.
Around 1,700,000 spent sources (including 1,150,000 at the GESI and 155,000 at the CEA, in INB 72) were listed as at 31 December 2007. It should be remembered that, for the purposes of the National Inventory, no conditioned equivalent volume is assigned to sources (except in the case of lightning rods). The results of the study on processes that will enable sources to be disposed of at existing or planned facilities, entrusted to the French National Radioactive Waste Management Agency (Andra) (see

Chapter 3, Box 3.1) will, for the next National Inventory, give a breakdown of these sources according to the management solutions identified to deal with them and to assess their conditioned equivalent volume, which will remain low compared with most of the categories of waste covered in the Inventory. The CEA's stock of spent sealed sources primarily comprises:

- high-level, medium-lived sources, such as cobalt-60, strontium-90 and caesium-137, including 4,183 items with total activity of around 20,000 TBq in 2007 (see Table 4.29);

Table 4.29: High-level, short- and medium-lived spent sealed sources belonging to the CEA

Radionuclide	Number of items	Activity as at 31/12/2007 (in TBq)
^{60}Co	783	8,000
^{137}Cs	3,384	7,700
^{90}Sr	6	1,400
Isotopic power generators	10	300

Source: CEA 2008

- low-level, long-lived spent sources. These include 276,000 items with estimated activity of around 25 TBq. Table 4.30 gives some examples of long-lived spent sources owned by the CEA.

Table 4.30: Examples of long-lived spent sealed sources belonging to the CEA

Radionuclide	Number of sources in 2007	Total estimated activity (in 2007)
^{226}Ra	2,592	150 GBq
^{227}Ac-Be	14	130 MBq
^{235}U	392	430 MBq
^{238}U	741	1.07 GBq
^{238}Pu	56,621	5.18 TBq
^{239}Pu	1,997	0.89 TBq
^{242}Pu	78	3.43 GBq
^{241}Am	80,497 198,793	0.4 TBq 0.69 TBq
^{244}Cm	1,162	48 GBq

4.8.5 Waste from dismantling operations after 2030

Only the dismantling of the Cis-Bio and LEA facilities could generate radioactive waste for this activity sector. This only represents a very small fraction compared with dismantling waste from the nuclear power plant industry or the CEA, and has not been specifically assessed.

4.8.6 Radioactive materials

One of the solutions considered for the management of some sealed sources at the end of life consists in "denaturing" them, i.e. recovering and recycling the active materials they possess. This applies to only a small number of sources. It also implies a need to develop special facilities to carry out this task.

At the moment, only the ATALANTE facility in Marcoule (CEA) would be suitable for meeting this demand.

The CEA/DAM facilities at the Valduc site could also recover tritium.

4.9 non-nuclear

industries using naturally-occurring radioactive material

The radionuclides contained in some natural mineral raw materials are processed in non-nuclear activities related to the chemical, metallurgy and electricity production industries. These activities also produce radioactive waste, which is mainly low- or very-low-level waste. Given that several of these activities, which were carried out in the past, caused radioactive pollution, this subchapter also introduces the subject of the chapter on contaminated sites (Chapter 5).

Map of the main non-nuclear industry sites (past and present) that use naturally-occurring radioactive materials or radionuclides

Rhodia plant - Radium-bearing waste stored in drums

4.9.1 Description of the activities

The activities

Some industries only work with naturally-occurring radioactivity. Sometimes the nature of the materials used or the industrial process tend to concentrate the radioactivity. Therefore, the radioactivity levels of the waste produced are sufficiently high to warrant special management. The regulations provide for a potential impact study to be carried out in such cases, to define the appropriate conventional or specific management solution.
It is hard to identify all the industries likely to produce this type of naturally-occurring radioactive waste. The manufacturer may not even wish to exploit the radioactive properties of the natural materials used. The process deployed may, in some cases, require raw mineral materials that have a high or low natural radionuclide content and it is quite possible that radioactivity is indirectly concentrated in the waste.
A typology of the industries likely to be producing naturally-occurring radioactive waste has been drawn up. This list is based on feedback regarding current and past industrial practices.

The activities in question include the following:

industrial oil and natural gas extraction and processing facilities

Depending on the nature of the prospected terrain, sand, muds or certain tools may be contaminated by daughter products of the natural uranium in the soil.

industrial coal combustion plants

In certain circumstances, the ash and slag left by burning coal concentrate the naturally-occurring radioactivity in the original ore (uranium, thorium and their descendants).

metal foundries, especially those using tin, aluminum, copper, titanium, niobium, bismuth and thorium ore

These particular ores sometimes contain radioactive elements that are concentrated in the residue, and which may be of the same chemical nature as the extracted metal (radioactive thorium, bismuth and niobium blended with the metal in its stable form), or different chemical elements;

foundries that work with monazite sand;

industries that manufacture articles or parts containing thorium;

industries that manufacture and use zircon and baddeleyite, primarily the refractory and abrasive ceramics industries

rare earth extraction and processing industries that work with natural minerals including monazite.

The above four industries work with thorium or its daughters. The radionuclides may simply be totally or partially transferred to the residue, or concentrated by precipitation phenomena due to the industrial processes employed.

I the phosphates industry, particularly the manufacture of phosphoric acid and fertilizers

The industrial processes produce solid waste (phosphogypsum), and also contaminated scrap metal when certain parts of the plants are eventually dismantled.

I the colour pigment industries, especially those that use titanium oxide

The chemical industry extracts colour pigments for paint (titanium dioxide) from natural ores: ilmenites and rutiles (ores with high titanium content). The initial thorium and uranium activity levels may be concentrated in the residue.

This list does not imply that the industrial sites mentioned in it produce or have produced radioactive waste as a matter of course. Furthermore, it is possible that an industrial sector not included in this list occasionally produces waste that may be considered radioactive. The industries in question must eventually submit a report on the waste they produce to the government, detailing the management solutions implemented.

4.9.2 Waste produced

Various activites produce or have produced radioactive waste, mostly very-low-level, which requires specific management solutions.

The industrial activities involved, which have gradually been included in the scope of Andra's surveys and are currently identified, carry out the following activities[3] :

- radium extraction and use of its properties (now ceased in France);
- use of the properties of thorium, including for the preparation and extraction of rare earths;
- fertilizer and/or phosphoric acid production;
- manufacture of titanium oxide for paint pigments;
- oil and gas extraction and processing.

This mainly involves plants and facilities that have now ceased production, except for nine sites that are still operating: La Rochelle, Le Pontet, Jarrie, Grand-Quevilly, Thann, Lacq, Saint-Faust, Monein-Pont d'As and Le Havre. In some cases, the materials have been removed and there is no waste left on site but the site is nonetheless considered contaminated and cleanup operations that may create additional waste are planned (see Chapter 5).

4.9.3 Scenario for the period 2008-2030

Industries still in operation

Now that the public authorities have defined the categories of professional activities potentially involved in handling naturally-occurring radioactivity, a more systematic programme to identify and examine specific cases needs to be conducted. Forecasting is particularly difficult because the possible producers of this type of waste are so far apart geographically and because, as the regulations change, more producers may be identified.

At Le Pontet in the Vaucluse, the silicates generated by the production of zirconium oxide are removed via a conventional management solution in light of the impact study that has been carried out (see Section 4.9.1).

3 This does not cover all the industries that may potentially produce waste that is naturally radioactive (technically enhanced or not), as described above.

Assessing the future production of radioactive waste, LLW-LL in this case, has only been possible for facilities belonging to Rhodia and Cezus, two of the leading players in the sector.
The **Rhodia rare earth extraction plant** in La Rochelle will continue to use raw materials produced from ores that have been processed to lower their activity level before being imported into France. The manufacturer considers the resulting "suspended particulate matter" (SPM) to be radioactive material that can be recycled (see Section 4.9.5). The amount of ultimate waste in the radium-bearing LLW-LL category that will be obtained after processing remains to be determined. In addition, RHODIA is now looking into processing crude thorium hydroxide (thorium separated from the rare earths as part of the chlorine process), which is seen as a recyclable radioactive material since it contains around 10% thorium. The quantity of waste that will result from this is thought to be around 9,000 m^3.
The **Cezus** plant in Jarrie, which makes **zirconium sponges** for nuclear power plant pipes, will produce an estimated average of 130 m^3 of radium-bearing waste a year during the period 2008-2030.
Apart from these two plants, the amount of VLLW and (radium-bearing) LLW-LL is difficult to estimate.

Rhodia plant – LLW-LL

Table 4.31: Sites that produce or have produced naturally-occurring radioactive waste (technically enhanced or not)

Industrial production	Raw material for the nuclide used	Name of site*		Operator
		Production stopped	On-going production	
Extracting, refining and/or conditioning radium for medical uses and for health and beauty products	Uranium ore	Ile-Saint-Denis Nogent-sur-Marne Gif-sur-Yvette Asnières Aubervilliers Arcueil (Institut du Radium) Paris 8th and 10th		Rothschild plant A. de L'Isle plant SNR plant Private AFTRP Universities Private
Application of luminous paint for night vision	Radium-226 and/or tritium	St-Nicolas-d'Aliermont Wintzenheim Beauchamp Colombes Paris 15th		Bayard plant SPW Lumina Private Private
Preparation and/or extraction of rare earths	Monazite or bastnaesite sand	Boucau Serquigny Pargny-sur-Saulx Thann		Reno Atofina Orflam-Plast Thann et Mulhouse
Thoriated magnesium alloys	Thorium-232	Arudy	La Rochelle	Rhodia Hondel Messier
Zirconium and/or uranium metallurgy	Thorium-232 and/or uranium-238	Le Pontet Loos	Jarrie	SEPR St-Gobain Cezus Chimie Tessenderlo
Phosphoric acid and fertilizers	Phosphate ore	Ambarès Bordeaux Douvrin Outer ring Le Pontet Les Roches Ottmarsheim Rogerville Sète Tarnos Tarnos Tonnay-Charente Boucau	Gd-Quévilly	Grande Paroisse Hydro Agri Fr Grande Paroisse Grande Paroisse A. de Rouen Port Sud fertilisant Rhône-Poulenc Pec Rhin Hydro Agri Fr Hydro Agri Fr Socadour Satec Secma Reno
Paint pigments (titanium oxides)	Rutile and ilmenite sand		Thann Le Havre	Millenium Chemicals
Oil and gas extraction and processing	Formation water from the crystalline basement		Lacq Saint-Faust Monein-Pont d'As	Total Exploration & Production France
Miscellaneous	Neutron generators	Limeil		Sodern

* Some of these sites are mentioned in the discussion of contaminated sites in Chapter 5.

Cezus plant

4.9.4 General results for 2007, 2020 and 2030

Table 4.32 shows waste stocks for the "Non-nuclear industries that use naturally-occurring radioactive material" activity sector at the end of 2007, the end of 2020 and the end of 2030.

Table 4.32: Waste stocks at the end of 2007, the end of 2020 and the end of 2030 in m^3 conditioned equivalent

	2007	2020	2030
LLW-LL	18,159	23,928	35,388
LILW-SL	14,430 including 14,270 already in a repository	14,430	14,430
VLLW	2,095 including 639 already in a repository	2,095	2,095

4.9.5 Radioactive materials

Thorium is considered to be recyclable in that it can be used in various industrial applications. It also has an energy potential. As at 31 December 2007, there were approximately 7,134 tonnes of thorium stored in the form of nitrate and hydroxides at the Rhodia site in La Rochelle.

Suspended particulate matter (SPM) is produced by the process used to neutralise chemical effluent produced at the Rhodia plant. On average, these SPMs contain 25% rare earth oxides.

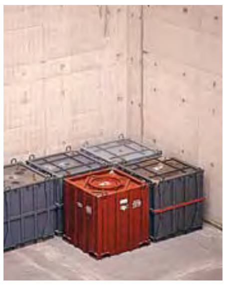
As at 31 December 2007, 21,672 tonnes of SPM, by-products of rare earth processing, were stored at the Rhodia site.

As for the phosphogypsum originally dumped in heaps (>25 million tonnes), recycling units processed this "secondary raw material" in the early 1980s to manufacture plasterboard for the building industry. A third of the phosphogypsum produced by the Grand-Quevilly plant was absorbed in this way.

research, production or experimentation centres working for the nuclear deterrent

4.10

This activity sector covers the CEA's Military Applications Division (DAM) centres and certain activities carried out by AREVA. It includes all activities related to the nuclear deterrent, together with the nuclear propulsion research facilities in Cadarache.



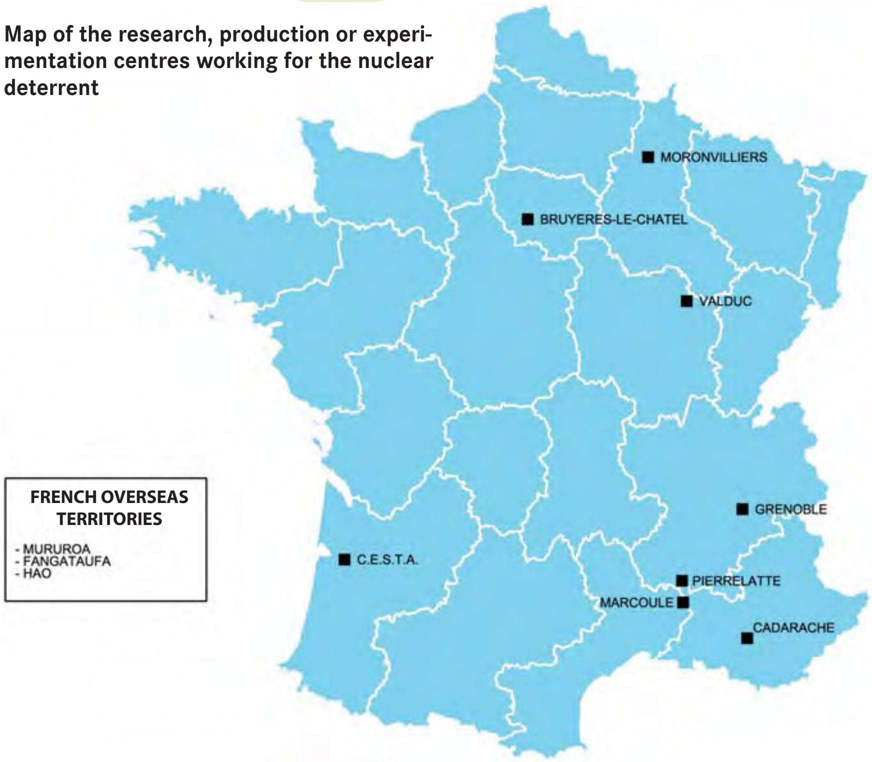
Metal container boxes being placed in a repository

Storage of tritiated waste at Valduc

Metal container box containing cemented waste

Tritiated waste storage facility at Valduc

Map of the research, production or experimentation centres working for the nuclear deterrent



Description of the activities and sites

CEA's Military Applications Division (DAM) designs, manufactures and services France's Defence System nuclear warheads. It is also responsible for dismantling nuclear weapons that have been taken out of service. In addition, it is in charge of the design and development of nuclear steam generators for the French Navy's fleet and of manufacturing reactor cores for these steam generators.

The sites in question are classified as Secret Basic Nuclear Installations (INBS).

The Bruyères-le-Châtel Centre and, in particular, the Valduc Centre, produce most of the sector's current waste. The following section describes the sites that produce or have produced radioactive waste.

DAM facilities in operation

Bruyères-le-Châtel

Since it was set up, the site manufactured nuclear devices that were tested in the Sahara and then in the Pacific between 1960 and 1996, and has followed up testing and research on the constituent materials.

Work on experimental devices ceased in 1997. Research and Development on nuclear materials has been transferred to the Valduc Center, with other materials focused on at Ripault, near Tours. The facilities in question are being dismantled and mainly produce VLLW and LILW-SL. Some specific and limited activities relating to physics and analysis are still carried out at the site.

Valduc

This Centre develops some components of nuclear weapons. It processes the radioactive materials (plutonium, uranium and tritium) for them and also carries out research on materials.

Its activities produce waste that is contaminated with alpha emitters and with tritium, amounting to a few hundred m^3 a year. Since there is no operational management solution for this waste, it is stored at the Valduc site, which can also occasionally take limited amounts of tritiated waste produced by other operators.

Moronvilliers

Explosives tests involving uranium depleted in isotope-235 are carried out at this military site.

The CESTA and TEE ("Terrain d'Expérimentation Extérieur", the external experimental ground)

CESTA, the Scientific and Technical Research Centre in Aquitaine (Centre d'études scientifiques et techniques d'Aquitaine), is a facility belonging to the CEA's Military Applications Division which is traditionally in charge of developing the industrial architecture of nuclear warheads for the nuclear deterrent. Explosives tests have been carried out there, some of which used uranium depleted in isotope-235.

Note:

The Vaujours military site was basically used as an experimental site for conventional explosives and munitions from 1947 to 1955.

Reclamation and cleanup operations were carried out in 1997 on the firing zones contaminated by past tests using depleted uranium and have now been completed. This site no longer belongs to the CEA's Military Applications Division.

AREVA facilities related to the nuclear deterrent

Marcoule

The Marcoule site houses the CELESTIN reactors and the Marcoule tritium extraction facility (ATM), both of which are operated by AREVA on behalf of the DAM.

Pierrelatte

The recycling and production plant (URE) supplies fuel for military purposes.

Cadarache

The nuclear propulsion facilities, operated by AREVA on behalf of the CEA, are used to develop, qualify and then provide maintainence for certain systems and equipment for nuclear steam generators for the French Navy's nuclear fleet. Covering a surface area of around twenty hectares, some of the facilities are subject to the regulations relative to installations classified for environmental protection, while five others are separate:

- AZUR, the experimental pile;
- the FSMC fuel production facility:
- the "RES reactor" facility, for which building work is in progress on the reactor module (criticality scheduled for 2011);

together with two facilities that have been closed, described in the section below:

- the Prototype on Land reactor (PAT), now being decommissioned;
- the New Generation Reactor (RNG), which has now stopped operating.

Facilities that have stopped operating

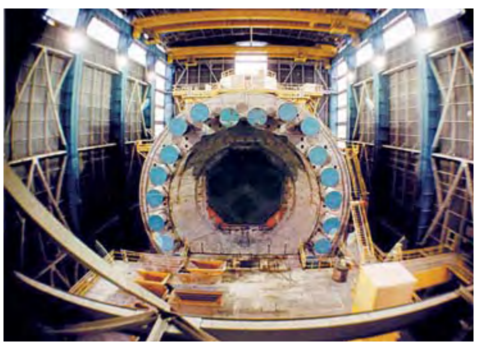
These produce waste according to the cleanup and dismantling schedule.

Since 2004, the CEA has acted as Project Owner for dismantling:

- **the UP1 plant at Marcoule (Gard)**, accounted for under the "fuel-cycle back-end" activity sector (see Subchapter 4.3). This plant extracted and purified plutonium for military use before processing certain irradiated fuel assemblies from the GCR series and from the CEA's research reactors.

The CEA/DAM (Military Applications Division) is in charge of dismantling operations at:

- **the "low, intermediate, high and very high" (activity) plants in Pierrelatte (Drôme).** The AREVA Pierrelatte facility produced enriched uranium for military use using the gaseous diffusion process and then nuclear fuel for both military and civilian use. The production of highly-enriched uranium fissile material for Defence purposes has ceased leading to the closure of four enrichment plants (low, intermediate, high and very high activity plants);
- **the G2 and G3 reactors at Marcoule.** Since the end of the 1950s, these reactors produced plutonium for the nuclear deterrent. Dismantling operations have now reached Level 2[4]. The graphite structures and miscellaneous waste produced during the dismantling operations (primarily products from a metal waste smelting furnace) have been stored in the sections that have yet to be dismantled;
- **the PAT and RNG reactors in Cadarache (13)**. In the case of the PAT, following the end of operating, pronounced in 1998; decommissioning operations were finalised in 2001. As for the RNG, the end of operating was prononced in 2006.



The G2 and G3 reactors at Marcoule

Other facilities operated on behalf of the DAM

Limeil-Brévannes

The last waste produced by SODERN, contaminated by tritium and resulting from the manufacture of neutron generators on behalf of the DAM, was sent to the Valduc site.

4 The International Atomic Energy Agency (IAEA) defines three dismantling levels, related to the final state of the facility.

The Pacific Test Centre

Between 1966 and 1996, the French Government tested nuclear weapons at the Pacific Test Centre (CEP), located on the Mururoa and Fangataufa Atolls in the South Pacific, on French Polynesian terrritory. The advanced base for the Pacific Test Centre was developed on Hao Atoll.
Nuclear tests were first carried out in the atmosphere (1966-1974), then underground in vertical boreholes drilled into the rocks of the coral crown (1975-1987) or under the lagoons (1981-1996).
The underground residual activity is given in the Geographical Inventory.

Mururoa Atoll

Between 1966 and 1974, France carried out 37 nuclear tests in the atmosphere and 5 safety trials in the atmosphere on this atoll, followed, from 1976 to December 1995, by 127 underground nuclear tests and 10 safety trials.

Fangataufa Atoll

Between 1966 and 1970, France carried out 4 nuclear tests in the atmosphere on this atoll, followed, between 1975 and January 1996, by 10 underground nuclear tests.

Hao Atoll

Major airport infrastructure and laboratories were built between 1963 and 1965 on Hao Atoll, where the advanced base for the Pacific Test Centre (CEP) was located.
The CEP facilities were dismantled between February 1996 and July 1998.

4.10.2 Waste produced

Waste produced by the DAM has two recurring characteristics. The quantities produced are small compared with civil production and the waste is almost entirely contaminated by alpha emitters or tritium.

ILW-LL

Mainly sludge and concentrates produced by the Valduc effluent treatment station in the past, injected and placed in metal drums, as well as technological waste awaiting shipment to Cadarache.

LILW-SL and VLLW

LILW-SL and VLLW produced by the CEA/DAM is generally sent to the LILW-SL and VLLW disposal facilities (CSFMA and CSTFA).

Tritiated VLLW

Metal drum of cemented sludge and concentrates

Nonetheless, one specific case is that of tritiated waste that is either too highly radioactive or releases too much gas to be suitable for disposal in its present condition at these facilities, given the risk of environmental contamination due to the tritium, which is a highly mobile element.
To deal with this situation, the Act of 28 June 2006 tasked the CEA with developing, by 31 December 2008, storage solutions for waste containing tritium with a view to reducing radioactivity levels prior to disposal in surface or near-surface facilities.
A report proposing storage solutions for all current and future tritiated waste for which no management solution exists at present, allowing for decay prior to disposal, was drawn up by the CEA and submitted to the French Ministry of Ecology, Energy, Sustainable Development and Territorial Planning Ministry (MEEDDAT) in December 2008 (see Box 3.2, Chapter 3).

4.10.3 Scenario for 2008-2030

The scenario adopted assumes that current production levels will remain the same. This is in line with expectations regarding the continuity of the nuclear deterrent. It follows that the centres reporting to CEA/DAM will produce a relatively constant volume of radioactive waste in coming years.
Forecasts include cleanup, dismantling (especially the start of dismantling the old GCR G2 and G3 reactors in Marcoule) and legacy waste recovery operations during the period.
Future simulation tools, primarily the megajoule laser at the CESTA site, will not radically alter the nature nor the quantities of waste currently being produced.
The major dismantling and legacy waste recovery programs for the Rhone Valley Defence facilities (Marcoule and Pierrelatte) undergoing decommissioning since 1997 (cf. Subchapter 4.3) will continue.

4.10.4 General results for 2007, 2020 and 2030

Table 4.33 shows waste stocks for the "Research, production or experimentation centres working for the nuclear deterrent" activity sector at the end of 2007, the end of 2020 and the end of 2030.
When vitrified HLW was produced for the purposes of the nuclear deterrent, it was produced at AREVA's fuel recycling facilities. As such, in line with the accounting method used for the Inventory, this waste is included under recycling activities (cf. Subchapter 4.3)

Table 4.33: Waste stocks at the end of 2007, the end of 2020 and the end of 2030 in m^3 conditioned equivalent

	2007	2020	2030
ILW-LL	81	81	91
LLW-LL	-	-	8 125
LILW-SL	26,277 including 22,352 already in a repository, and 2,840 tritiated waste (not in a repository)	32,684	37,358
VLLW	31,925 including 40,446 already in a repository	46,925	54,925

This comment applies to all the other management solutions; the only waste counted here is that strictly related to the *activities* described in this subchapter.

4.10.5 Waste from dismantling operations after 2030

The major dismantling operations to be pursued after 2030 are:

- dismantling the CELESTIN reactors, the tritium extraction facility and the G2 and G3 reactors to IAEA Level 3, at the Marcoule site;
- dismantling the experimental AZUR pile and the FSMC fuel production facility, at the Cadarache site;
- dismantling certain facilities at the Valduc site.

In Pierrelatte, all the DAM's facilities will have been dismantled by 2030.
For these operations, an assessment of the waste produced has been drawn up (Table 4.34), excluding the nuclear propulsion facilities in Cadarache, regarding which the assessment is currently being consolidated.

Table 4.34: Dismantling waste after 2030 in m^3 conditioned equivalent

LLW-LL	6,000
LILW-SL	6,000
VLLW	20,000

4.10.6 Radioactive materials

France's National Defence sector uses fuel for reactors that produce certain materials, as well as for test reactors and onboard nuclear propulsion reactors.
The National Inventory cannot give details of the location or composition of these fuel stocks as the data is classified. They make up a small proportion of the fuel generated by the nuclear power plant and civil research sectors.
The National Defence sector's spent fuel is currently in storage and its future (disposal or processing) is undecided. Waste stocks in existence at the end of 2007, the end of 2020 and the end of 2030 are shown in Table 4.35.

Table 4.35: Spent fuel produced by the National Defence sector in tonnes at the end of 2007, the end of 2020 and the end of 2030

2007	2020	2030
141	230	298

The quantities of military-grade plutonium, enriched uranium and tritium are classified Defence data.

Defence sector

4.11 Centres

This activity sector covers professional activities relating to French National Defence (excluding nuclear deterrent centres covered in the previous chapter) and that hold radioactive waste, whether directly attached to or working for the Ministry of Defence.

Map of French Defence centres: DGA, SSA, Army/Airforce/Navy/Gendarmerie

☐ Sites presented on sheets in the Geographical Inventory

■ Sites presented in tables in the Geographical Inventory

The Redoutable submarine

4.11.1 Description of the activities and sites

Material taken out of service by the armed forces

All the armed forces have equipment that draws on the properties of radioactivity, especially for night vision. These worn or now obsolete items of equipment are waste, and are listed for each National Defence establishment (around a hundred Army, Air Force, Navy and Gendarmerie establishments).
This equipment is generally small, such as radium or tritium compasses, sights, luminous plates and dials, together with various monitoring devices. Some aircraft engine parts which have been withdrawn from service and contain thorium are also listed (magnesium-thorium alloy housing, for example).
Several establishments have grouped this waste by category to centralise and streamline the way in which it is managed. Thus, the French Armament Procurement Agency (DGA) in Arcueil and Le Bouchet, as well as the Air Force establishment in Châteaudun, accept thoriated magnesium alloy parts. The army base at Saint-Priest takes compasses and luminous plates.

The Armed Forces Health Services (SSA)

See Subchapter 4.7 on the medical sector.

French naval ports

Servicing and maintenance operations for naval nuclear steam generators (French nuclear-powered submarines and aircraft carrier) produce waste at the naval dockyards in Cherbourg, Crozon/Ile Longue and Toulon.

The DCN shipyards centre

This centre, located in Indret, makes components for nuclear steam generators for the French fleet in collaboration with AREVA. Reactor cores taken out of service are stored in Cherbourg.

Test Centres that use uranium depleted in isotope 235



The Redoutable: cross section of the submarine's reactor unit

Radioactive waste from experiments and tests[5] performed on weapons[6] containing uranium depleted in isotope-235 is held at the Bourges and Gramat centres.

5 In France, strict procedures govern testing of munitions containing uranium. They are only carried out in enclosed facilities that are regularly monitored by the Armed Forces' Radiological Protection Service (SPRA).

6 Metal uranium is used in weapons, not because of its radioactivity, but for its mechanical and pyrophoric properties.

4.11.2 Waste produced

The Armed Forces' radiological protection service (SPRA) has drawn up a list of 114 establishments that produce or hold radioactive waste (Table 4.36). The detailed tables given in the Geographical Inventory reveal the diverse nature of the waste, which mainly consists of small items of equipment incorporating luminous paint containing radium or tritium (compasses, plates, sights, dials, etc.) that have been taken out of service. They list 28 types of object.

In addition, Naval Propulsion declares the waste produced by the nuclear steam generators in service (submarines and aircraft carrier) at the Cherbourg, Crozon/Ile Longue and Toulon dockyards.

Table 4.36: French Defence centres (DGA, DCN, Armed Forces)

Location	Comment
114 centres listed in 20 regions of France The main sites are listed below	See detailed survey of sites and waste in the Geographical Inventory
Arcueil **Le Bouchet** **Châteaudun** **Saint-Priest**	Centralised management sites for equipment taken out of service
Bourges **Gramat**	Depleted uranium
Cherbourg **Crozon Ile Longue** **Toulon** **La Montagne – Indret Site**	Naval propulsion

4.11.3 Scenario for 2008-2030

It is assumed that the radioactive waste produced by the Armed Forces will continue at current levels.

4.11.4 General results for 2007, 2020 and 2030

Table 4.37 shows waste stocks for the "Defence" sector at the end of 2007, the end of 2020 and the end of 2030.

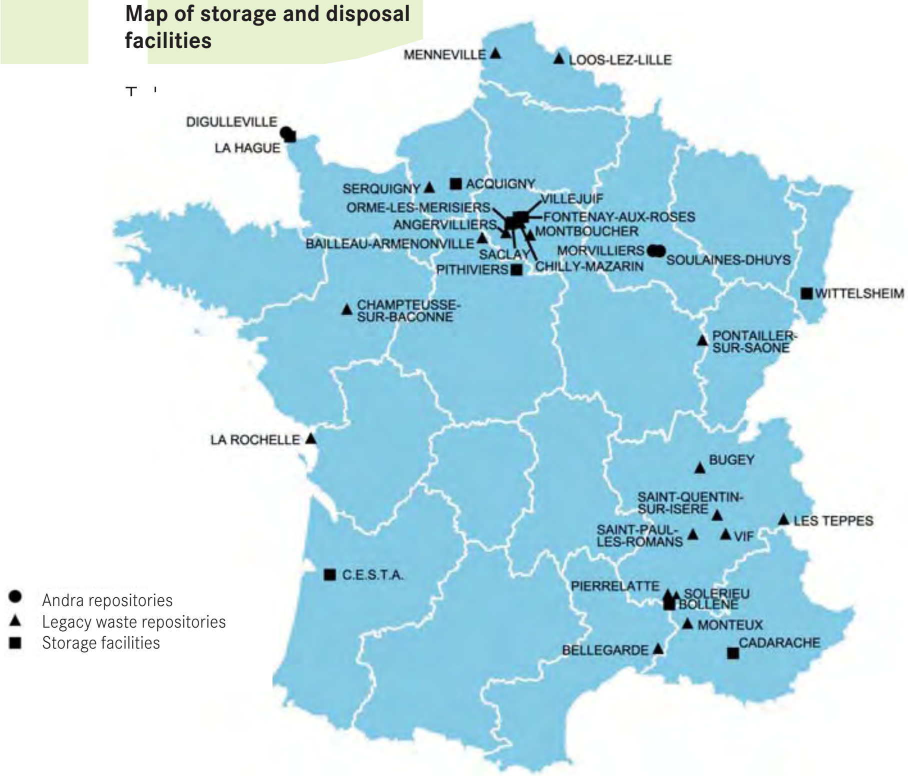
Table 4.37: Waste stocks at the end of 2007, the end of 2020 and the end of 2030 in m^3 conditioned equivalent

	2007	2020	2030
LLW-LL	435	598	723
LILW-SL	12,749 including 12,532 already in a repository	13,603	14,218
VLLW	1,341 including 397 already in a repository	9,141	14,541

4.12 storage and disposal facilities

This activity sector includes Andra's disposal and storage facilities, storage facilities for waste not produced by the site operator and legacy waste repositories.

Map of storage and disposal facilities



storage facilities listed under this activity sector are those which, on a provisional basis, take in waste produced by other industrial activities. For example, this is the case regarding certain storage facilities run by the CEA or Andra, which take radioactive waste collected from private individuals (such as radium needles and radioactive lightning rods).

On the other hand, however, the storage facilities used by industrial firms to manage their own waste pending disposal are not included here. Such storage facilities are covered in Chapter 3 and in Appendix 4 in the case of HLW and ILW-LL.

Insofar as regards waste repositories, this activity sector includes extremely different types of site.

Some have been specially designed to take radioactive waste: this is the case regarding Andra's disposal facilities, which take waste that satisfies certain technical specifications and acceptance criteria.

Other facilities include industrial facilities desgned for the disposal of conventional waste, which may have received in the past, or may still receive, waste containing

The CSM waste disposal facility

The CSFMA disposal facility

The CSTFA disposal facility

Unloading a metal container box (CSFMA disposal facility)

Lowering a concrete package into a cell (CSFMA disposal facility)

Metal drums being disposed of (CSFMA disposal facility)

very low levels of radioactivity. It should be remembered that disposing of radioactive waste at conventional disposal facilities is solely permitted under the regulations in the case of waste that is naturally radioactive, possibly technically enhanced, and if its activity level does not require any special radiological protection measures (see Chapter 1). The requirements for accepting such waste are defined in a Ministerial Circular dated 25 July 2006.

Other repositories involve sites that are usually located in proximity to nuclear facilities and plants where, in the past, radioactive waste that the operator or holder did not plan to remove at the time of submitting its declaration for the National Inventory was disposed of in mounds, backfill or lagoons.

The latter two types of site, which are not managed by Andra, are known as "legacy waste repositories".

Last, some of the sites mentioned in this subchapter relate to former practices, which were authorised at the time but which are now considered unacceptable. This is the case insofar as regards sites where waste was dumped at sea.

Note: sites in French Polynesia (Mururoa, Fangataufa and Hao), which come under the nuclear deterrent activity sector, are also considered as legacy waste repositories. These are described in Subchapter 4.10.

Andra's disposal and storage facilities

The CSM waste disposal facility (Manche)

This was the first French LILW-SL surface disposal facility. It was licensed by decree in 1969. It covers a surface area of approximately 15 hectares and is sited near AREVA's La Hague spent nuclear fuel processing plant.

It was operated until June 1994 and has accommodated approximately 527,000 m^3 of waste. It is now protected by a waterproof membrane and entered into the official post-closure monitoring phase in January 2003.

The CSFMA low- and intermediate-level waste disposal facility (Aube)

Commissioned in January 1992, the CSFMA low- and intermediate level waste disposal facility has taken over from the CSM disposal facility. This facility is designed to isolate radioactive waste from the environment for the time it takes to decay to a level at which there is no longer any risk to the population or the environment.

Waste packages are placed in reinforced concrete cells (engineered structures) and then immobilised with gravel or concrete slurry. A reinforced concrete slab seals these engineered structures once they have been filled. Once full, it will be capped by a layer several metres thick, as for the CSM facility.

The CSFMA disposal facility currently receives approximately 13,000 m^3 of waste packages a year. As at 31 December 2007, 208,053 m^3 of waste packages had been disposed of there. With capacity of a million cubic metres, the CSFMA disposal facility will still be able to take waste packages for several decades to come.

Disposal activities can also generate waste (through operations at the centre, inspecting the packages received, maintenance, etc.). The volume of such waste is, however, very small. For example, operating at the CSFMA disposal facility produces around 50 m^3 of LILW-SL every year.

Further information on the CSFMA disposal facility can be found in Appendix 3.

The CSTFA very-low-level waste disposal facility (Aube)

In France, the public authorities have opted for a specific management solution for waste from so-called "nuclear zones" of basic nuclear installations, regardless of the activity level involved.

Unlike international practices, there is no "clearance level", in other words, no level of radioactivity below which such waste is no longer considered as radioactive. The only factor that counts is whereabouts it comes from within the installation. For the least radioactive waste, described as "very-low-level" waste (VLLW), Andra has operated a dedicated centre in Morvilliers (Aube) since August 2003. The capacity of this centre is 650,000 m^3 and it is located close to the CSFMA disposal facility. As at 31 December 2007, 89,331 m^3 of waste packages had been disposed of there.

The waste is disposed of in cells dug into the clay. The activity of the short- and medium-lived radionuclides will have decayed considerably within a few decades. In the long term, long-lived radionuclides and chemicals will be contained thanks to the retention properties of the clay formation.

Further information on the CSFTA can be found in Appendix 3.

Unloading big-bags (CSTFA disposal facility)

Shuttle truck between buildings (CSTFA disposal facility)

Andra's interim storage sites

- **The Bollène platform (84),** managed by SOCATRI, carries out sorting and storage operations on waste from "small-scale nuclear activities" waste producers. Information regarding its remaining capacity to receive waste and occupied capacity at the end of 2007 is given in Chapter 3.
- **The Centre de Regroupement Nord (CRN),** located in the CEA's Saclay research facility, groups together waste from the Medical, Research and Industry sectors.

Waste storage areas at CEA sites

The **CEA Centres, especially Saclay and Cadarache, accept miscellaneous waste produced by others for storage,** for historical reasons and due to their expertise. The disposal facilities for this waste are still at the planning stage (radium-bearing waste and spent sealed sources). Approximately 155,000 sealed sources (see Subchapter 4.8), from a variety of origins, are stored at INB 72 in Saclay. Earth from the cleanup operations at the radium-contaminated Bayard sites, old residue from the Rhône-Poulenc rare earth production plant in La Rochelle and radioactive lighning rods are stored at Cadarache.

Legacy waste repositories

Conventional waste disposal facilities [7]

Operators other than Andra manage a number of centres that receive or have received, regularly or occasionally, waste containing low levels of radioactivity usually measuring no more than a few Bq/g. The authorities do not consider the latter to be radioactive waste, since it was possible to dispose of it via a conventional solution, in accordance with the conditions at the time. Such sites are not directly covered by the National Inventory but are mentioned here as a reminder. It is thought that around 140,000 m^3 of low-level radioactive waste has been disposed of at these sites.

Waste placed in these repositories in the past came partly from the CEA's research centres (dismantling waste, and earth and rubble from various cleanup operations).

There are twelve sites of this kind listed in the National Inventory. They are located in the following places:

- Angervilliers in the Essonne;
- Bailleau-Armenonville (Eure-et-Loir);

[7] The majority of these sites are described in the Geographical Inventory as 'facilities designed to receive hazardous waste" or "facilities designed to receive non-hazardous waste", in compliance with the Orders of 30 December 2002 and 19 January 2006. They were previously known as "dumps" or "landfill sites".

- Bellegarde (Gard);
- Champteusse-sur-Baconne (Maine-et-Loire);
- Freney (Les Teppes) (Savoie);
- Menneville in (Pas-de-Calais);
- Monteux in (Vaucluse);
- Pontailler-sur-Saône (Côte-d'Or);
- Saint-Paul-les-Romans (Drôme);
- Saint-Quentin-sur-Isère (Isère);
- Solérieux (Drôme);
- Vif (SERF waste dump) (Isère).

Of these sites, only Bellegarde in the Gard still receives enriched naturally-occurring waste, under conditions compliant with the Ministerial Circular of 25 July 2006.

Other repositories involve sites that are usually located in proximity to nuclear facilities and plants where, in the past, radioactive waste that the operator or holder did not plan to remove at the time of submitting its declaration for the National Inventory was disposed of in mounds, backfill or lagoons.

For example, VLLW from dismantling the former Le Bouchet plant, with average radium and uranium content comparable to that found in the natural environment (up to 3 Bq/g), was used in roadworks for the A87 motorway at Chilly-Mazarin (91) during the 1970s. In addition, waste from the Rhodia plant (formerly Rhône-Poulenc), which was also contaminated with low levels of thorium-232 (48 Bq/g) and uranium-238 (6 Bq/g), was used, along with other materials, as backfill for the port facilities at La Pallice in La Rochelle (Charente-Maritime).

At the end of 2007, sites of this type listed in the National Inventory were as follows:

- the Pierrelatte mound (Drôme);
- the Bugey mound (Ain);
- the former dump beneath the ATOFINA plant buildings in Serquigny (Eure);
- Vernay lagoon in Loos-Lez-Lille (Nord);
- La Pallice port in La Rochelle (Charente-Maritime);
- the Montboucher mound (Essonne);
- the A87 motorway at Chilly-Mazarin (Essonne).

In addition to the above, there is also the site in La Rochelle (Chef de Baie plant) where solid residue was used as backfill. This site is not classified under the "Storage and disposal facilities" sector because waste (radium-bearing residue or RRA) is still produced there; it comes under the "Non-nuclear industries that use naturally-occurring radioactive materials" activity sector.

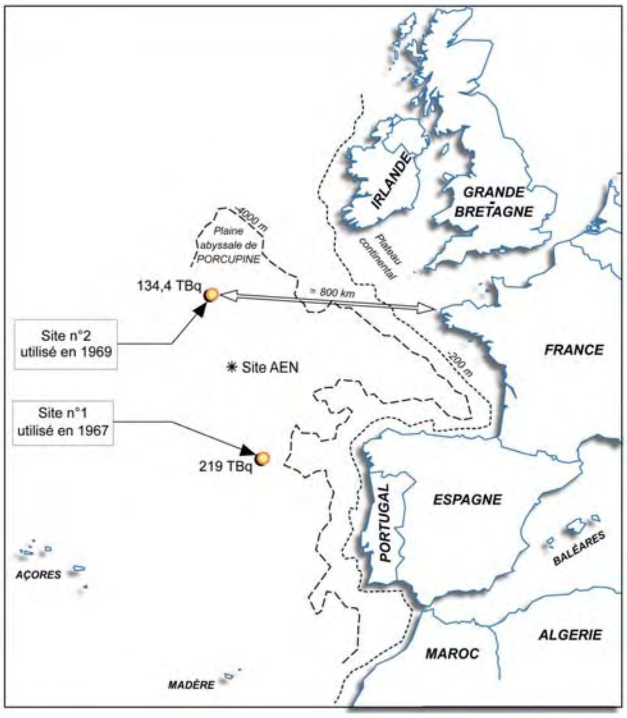
At the end of 2007, an estimated 144,000 m^3 of waste had been disposed of at all these sites.

The Pierrelatte mound, which became AREVA property on 1st January 2007, now contains around 15,000 m^3 of waste produced by entities other than AREVA and disposed of between 1964 and 1977. Diffusion barriers, fluorites, sludge and miscellaneous waste from plants producing weapons-grade enriched uranium and related facilities can be found at this site. AREVA has decided to transfer the diffusion barriers (around 800 m^3) to a suitable disposal facility by 2013.

Waste dumped at sea

At the end of the 1960s, France took part in two series of offshore experiments, coordinated by the OECD, to dump radioactive waste in the Atlantic at a depth of 4,000 metres. At the time, there were no surface repositories. The waste consisted of 46,396 drums of settlement sludge from the Marcoule treatment plant, with total mass of about 14,200 tonnes and a radioactivity level of 354 TBq. This activity level is marginal compared to more intensive sea-dumping practices on the part of the United Kingdom, Switzerland and, to a lesser extent, Belgium and the Netherlands. International conventions now ban this practice. Appendix 5 describes the practice of dumping waste at sea in detail.
No more radioactive waste has been dumped in the Atlantic Ocean since 1969.

Radioactive waste dumped by France in the Atlantic Ocean



France = 0.8% (of all radioactive material dumped in the EAST Atlantic)

OFFSHORE SITES WHERE FRENCH WASTE WAS DUMPED
- Year: 1967 and 1969
- Number of packages 46 396
- Mass: 14,200 tonnes
- Total activity: 353 TBq (8 TBq for α and 345 TBq for $\beta\gamma$)

* ZONE USED BY THE NEA BETWEEN 1971 AND 1982
123,000 waste packages, 30,684 TBq for α

Sources: IAEA – March 1991, AUGUST 1999/Academy of Sciences 1985

radioactively contaminated sites

5

5.1 definition of a radioactively contaminated site

The Interministerial Circular of 17 November 2008 [I] gives the following definition:
"A radioactively contaminated site is any site, either abandoned or in operation, where natural or artificial radioactive substances have been or are being used or stored under conditions such that the site poses risks to human health and/or the environment."
The observed contamination must be attributable to one or more radioactive substances as defined in Article L. 542-1-1 of the Environmental Code, i.e. "any substance containing natural or artificial radionuclides whose activity or concentration justifies radiological protection monitoring."

This new interministerial circular replaces the one dated 16 May 1997, but without substantially modifying the regulatory definition of a radioactively contaminated site.

A contaminated site is therefore characterised as having been subjected to an uncontrolled dispersal of radioactive substances, the effects of which are incompatible with current public health and environmental protection regulations. This definition is based explicitly on the concept of health risk, which is directly dependent on site usage.

The mere presence of natural or artificial radioactivity does not necessarily mean that a site is radioactively contaminated. A site may contain detectable traces of natural or artificial radionuclides without requiring the implementation of specific measures (absence of risk). Such traces of radionuclides in the environment may be due to various causes, including industrial or traditional work activities conducted on-site, or external contamination.

[I] Interministerial Circular of 17 November 2008 regarding the general interest missions entrusted to Andra, the take-over of certain radioactive waste and the management of radioactively contaminated sites.

strategy for radioactively contaminated sites

5.2

National policy for the management of contaminated sites

The new circular specifies that "the management of a radioactively contaminated site must be consistent with the national policy regarding contaminated sites and soils as defined in the circular issued by the Minister for Ecology on 8 February 2007 for the prevention of soil contamination and the management and rehabilitation of contaminated sites."
This national policy places particular emphasis on the principle of risk management according to site usage.
As a result, site management procedures may vary depending on the sensitivity of site reuse conditions. For example, cleanup operations will be much more extensive if a site is intended for the construction of housing rather than just a car park, provided that the same use is guaranteed over time (e.g. via easements).
Defined and enforced by the public authorities, this policy is also largely based on concepts applicable to chemically contaminated sites.
The public authorities have set up an organisational structure to handle issues related to contaminated sites. The General Directorate for Risk Prevention of the Ministry of Ecology, Energy, Sustainable Development and Territorial Planning (MEEDDAT) is responsible for defining general government policy regarding chemically or radioactively contaminated sites. The Nuclear Safety Authority (ASN) is also concenred by radioactively contaminated sites as part of its general mission to ensure the protection of the public and workers against ionising radiation.

The policy for the management of contaminated sites is built around two main concepts:
- risk analysis and management, rather than focusing on intrinsic contamination;
- site management according to present or future use.

A course of action is decided after assessing the risk the site poses to the public. Cleanup requirements and objectives are therefore determined according to the potential risks associated with the planned use of the site.
Cleanup operations are not necessarily intended to eliminate all contaminants, which in any case is not always possible. Measures such as on-site confinement of radioactivity, groundwater monitoring, usage restrictions, etc. may be adopted depending on the situation.

Therefore, on-site operations do not necessarily involve the removal of radioactive waste. Nevertheless, since experience shows that numerous cleanup operations have led to the removal of such waste (e.g. contaminated land), the National Inventory of Radioactive Materials and Waste currently aims to identify all sites that have been or could be subject to cleanup operations.

Decisions and assessments are based on site characterisation data, including radiological maps, soil and groundwater sample analyses and, in the specific case of sites contaminated with radium, analyses of radon content in indoor air. Radon is produced as a result of radioactive decay of radium.

When a site is identified as radioactively contaminated, cleanup operations are generally considered, either at the request of the site owner or at the request of the public authorities if the site owner has gone out of business (e.g. further to a liquidation order). In the latter case, the Act of 28 June 2006 (see below) enables the public authorities to delegate project ownership to Andra.

Operationally speaking, Andra intervenes on sites where the owners are no longer in business, upon requisition by the public authorities. This requisition generally takes the form of a prefectoral order. The prefect concerned issues the order after authorisation by the Minister for Ecology.

Operations are conducted in close cooperation with relevant local administrations: Regional Directorates for Industry, Research and the Environment (DRIRE), Nuclear Safety Authority (ASN) and Departmental Directorates for Health and Welfare Services (DDASS).

General interest missions entrusted to Andra and CNAR

In 2006, the legislative authorities decided to define a clear framework for Andra's cleanup operations.

Article 14 (points 1 and 6) of Act 2006-739 of 28 June 2006 concerning the sustainable management of radioactive materials and waste defines the content of the general interest missions entrusted to Andra, with three main objectives:

- compiling the National Inventory of Radioactive Materials and Waste;
- handling certain diffuse nuclear waste, particularly in cases where members of the public who have strictly nothing to do with the use of radioactivity find themselves in the possession of radioactive objects (e.g. through inheritance or proximity), sometimes without even realising that the items in question are radioactive (radium objects, needles, fountains, etc.);
- rehabilitating radioactively contaminated sites where the owners have gone out of business, and handling the resulting waste. Article 15 of this Act further establishes the principle of state funding for general interest missions entrusted to Andra under Article 14 above (points 1 and 6). Prior to this Act, Andra's action was defined in the Circular of 16 May 1997 (now repealed) and via two specific funding mechanisms, i.e. the agreement on orphan contaminated sites (SPO) and the radium decontamination fund. It should also be noted that in certain cases Andra contributed its own resources.

These two funding mechanisms enabled the completion of significant operations but were restricted by their limited scope (type and limited scale of operations carried out) and their temporary nature.

The CNAR comprises representatives from authorities, technical institutes and associations, as well as elected officials and two qualified specialists.

They have now been replaced with an annual public subsidy effectively securing the funding of operations and therefore allowing for long-term planning based on site priority.
The National Commission for Radioactivity Assistance (CNAR) was created in order to decide on the use of this public subsidy, including fund granting priorities, contaminated site remediation strategies and waste management policies.
Chaired by the Chief Executive Officer of Andra, the CNAR includes representatives from public authorities (Nuclear Safety Authority [ASN], General Directorate for Risk Prevention [DGPR], General Directorate for Energy and Climate [DGEC], General Directorate for Health [DGS]), public technical institutes (ADEME, IRSN) and environmental associations (France Nature Environnement, Robin des Bois), as well as elected officials (one official appointed by the Association of French Mayors [AMF]) and two qualified specialists (one representative from a public real estate institute and one cleanup specialist).
The CNAR was created through deliberation by Andra's Board of Directors in April 2007. It meets approximately every three months to examine the cases submitted to it.

Cleanup operations in Gif-sur-Yvette

Various contaminated products (Isotopchim site)

origins of radioactive contamination: a few examples

5.3

Contaminated sites are mostly the result of past industrial activities, at a time when there was not yet a full and shared understanding of the potential risks associated with radioactivity.

A site can become radioactively contaminated due to various types of causes.

Facilities that handle natural or artificial radioactive materials are currently classified as basic nuclear installations (INB) or facilities classified for environmental protection (ICPE), depending on the activity levels involved. Within this regulatory framework, they undergo strict inspection procedures to limit releases to acceptable levels and to prevent accidents. Cases of non-compliance with regulations or accidents causing radioactive contamination are therefore relatively rare in facilities currently in operation.
Contaminated sites are mostly the result of past industrial activities, at a time when there was not yet a full and shared understanding of the potential risks associated with radioactivity. Regulations at the time could authorise or tolerate activities that would be prohibited today. In such cases, insufficient precautions when handling radioactive products may have resulted in site contamination. Other causes may include poor management of the termination of industrial activities, with possibly contaminated production residues being abandoned on site.

The majority of contaminated sites can therefore be associated with legacy industrial activities, some of which are discussed below, although not exhaustively.

Radium extraction for medical and parapharmaceutical use, from the early 20th century to the late 1930s.

The discovery of natural radioactivity by Henri Becquerel and Pierre and Marie Curie (joint Nobel prize winners in 1903) soon aroused interest in the therapeutic properties of radiation. As of 1901, the first applications of radium for healing diseased tissues (particularly inflammations) were considered. In 1906, it was observed that cancer cells were more sensitive to radiation than healthy cells. World War I witnessed the development of new therapeutic applications, with radiation used to accelerate the healing of wounds.

This new craze for the therapeutic virtues of radioactivity led to the development of a genuine radium industry in France, with the creation of factories, extraction and refining plants and preparation and conditioning facilities. Radium extraction activities were pursued in France until the 1920s, effectively coming to an end when Belgium began to import low-cost radium from Congo.
In this context, the use of radium was extended beyond the medical field to include parapharmaceutical applications (powders, poultices, pomades) as well as some quite extravagant applications, from today's perspective ('radium wool', etc.).
As of the 1940s, the growing awareness of the risks associated with the handling of radioactive materials, and the discovery of the first artificial radionuclides, gradually led to the end of the radium industry. The last applications, until 1962, concerned the production of lightning rod heads (see Subchapter 4.8) and radioluminescent paints (see below). Today, a few sites formerly occupied by extraction or production plants are still contaminated with radium and remainunder the control of public authorities.

Production and application of night vision paints.

Night vision requirements are mainly associated with military activities (compass sights, dials, signalling) and the clockmaking industry (luminous dials and hands for alarm clocks and watches).

Until 1962, radium was used for the production and application of radioluminescent paints. It was subsequently replaced with tritium. Production sites may have been contaminated with either one of these radionuclides, generally due to practices that are no longer acceptable today (on-site burning of contaminated waste, handling with little or no precaution). This is particularly the case with the Bayard site (formerly Radium Light) in Saint-Nicolas d'Aliermont (Seine-Maritime), which has now been cleaned up.

Industries using ores such as monazite or zircon.

These ores contain variable proportions of naturally radioactive elements (e.g. thorium-232 and its decay products) and are useful for the extraction of rare earths, an activity already discussed in Subchapter 4.9. During rare earth extraction, the natural radioactivity is concentrated in the residues. The Orflam-Plast site in Pargny-sur-Saulx (Marne) is an example of an old flint factory where cerium extraction led to on-site deposition of thorium-bearing residues.

Thorium-232 and its decay products, including radium-228, are also useful (e.g. incandescent tubing for public gas lighting systems, abrasives, metallurgical applications).

5.4 identification of contaminated sites

The identification of legacy contaminated sites is a difficult task, since historical records of industrial activities in a given site tend to be lost over the years. Andra contributes to the identification of forgotten sites via historical surveys of industrial activities, now at an end, but possibly causing radioactive releases to the environment in the past, particularly in the case of the radium industry.

The High Committee on Transparency and Information on Nuclear Safety (HCTISN) has recently issued recommendations on the harmonisation of public disclosure on the management of contaminated sites and soils. In particular, the HCTISN recommends that "the BASIAS website developed by the Ministry for Ecology and devoted to old industries or service activities should be extended to cover industrial sites potentially affected by radioactive contamination."

The methodology implemented to expand the website is mainly based on the use of old archives. This is therefore comparable to the historical surveys previously conducted by Andra.

It is important to maintain a record of cleaned-up contaminated sites, particularly if usage restrictions have been imposed. Andra helps to maintain this collective memory by publishing a regularly updated list of contaminated sites in the National Inventory.

inventory of radioactively contaminated sites

5.5

Table 5.1 shows a list of all the sites known to Andra as having been identified as contaminated further to radiological investigations, regardless of site activity status (legacy or current) and regardless of the radionuclides considered. The sites listed have been divided into the following categories:

- sites awaiting or currently undergoing cleanup: A = 24 sites;
- cleaned-up sites with waste stored on-site and awaiting removal: B = 6 sites;
- cleaned-up sites with or without easements: C = 30 sites, listed for reference.

The classification shown in table 5.1 may be subject to modifications, e.g. if a site is cleaned up or if additional cleanup is required.

The Geographical Inventory provides additional information on the sites listed, including detailed record sheets for nine sites where waste has been stored since late 2007.

The list is relatively short in comparison, for example, with the list of chemically contaminated sites maintained by the Ministry of Ecology, Energy, Sustainable Development and Territorial Planning (MEEDDAT) via the BASOL inventory (www.basol.environnement.gouv.fr).

Radioactively contaminated sites potentially located within the perimeter of nuclear facilities are not listed here, since they are governed by a strict regulatory framework and are therefore not considered as contaminated in the sense defined earlier.

prospects for the period 2008 - 2030

5.6

Cleanup operations often concern small sites on which housing has been built. These operations generate a few tens of m^3 of very-low-level waste (VLLW) and a few m^3 of low-level, long-lived waste (LLW-LL) per year. Cleanup operations concerning industrial wastelands remain rare and may generate several hundred m^3 of VLLW and several tens or hundreds of m^3 of LLW-LL.

The National Inventory is based on a production forecast of approximately 150 m^3 per year for each of these waste categories (VLLW and LLW-LL). This estimate is particularly uncertain, because it largely depends on the type of action to be implemented for each site.

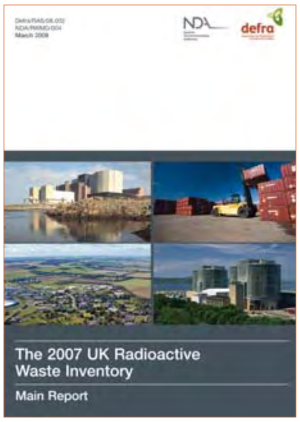
Table 5.1: List of contaminated or formerly contaminated sites

Environment	Name	Category (late 2007)	Owner
Industrial wasteland	Ganagobie	A	Isotopchim
	Pargny-sur-Saulx (buildings)	A	Orflam Plast
	Pargny-sur-Saulx (banks)	C	Orflam Plast
	Saint-Nicolas-d'Aliermont	C	Bayard
	Itteville-Vert-le-Petit/ Le Bouchet (old INB)	B	SNPE
Industrial site partially or completely occupied by facilities in operation	Boucau	B	Reno
	Colombes	A	Sol Essai
	Romainville	C	Aventis
	Beauchamp	C	Lumina
	Saint-Clair-du-Rhône (Roches)	C	Rhodia chimie
	La Rochelle	C	Rhodia Electronics
	Serquigny	B	Atofina
	Saint-Nicolas-d'Aliermont	C	Couaillet Mauranne
	Besançon	C	Lip
	La Roche de Rame)	C	Planet
	Pierrelatte	C	Radiacontrôle
	Wintzenheim	B	Jaz
	Valognes	C	AREVA
	Donges	C	Total Fina Elf
	Bonneuil-sur-Marne	C	Port Authority Bonneuil
	Rogerville	B	Port Authority Le Havre
	Grand-Couronne	C	Grande Paroisse
Legacy site associated with radium production and usage	Nogent-sur-Marne	A	Former school
	Gif-sur-Yvette	A*	Private address (subdivision)
	Ile-Saint-Denis	A	Charvet
	Ile-Saint-Denis (berges)	A	Voies navigables de France
	Arcueil	A	Université de Paris VI
	Clichy	A	Port Authority + DDE
	Aubervilliers	C	AFTRP
	Paris 5th	C	Private address
	Paris 5th	A	Private address
	Paris 7th	C	Private address
	Paris 8th	C	Private address
	Paris 8th	A	Private address
	Paris 8th	C	Private address
	Paris 10th	C	Private address
	Paris 16th	A	Private address
	Salagnac	C	Cité de Clairvivre
Private house or property	Nogent-sur-Marne	A	Yab
	Gif-sur-Yvette	A	Federal Mogul
	Asnières-sur-Seine	C	Private address
	Bandol	A	Private address
	Bandol	A	Private address
	Bandol	C	Private address
	Paris 15th	C	Private address
	Colombes	C	Lumina
	Annemasse	A	Private address
	Paris 14th	A	Private address
	Huningue	A	Private address
	Chivres	A	Private address
Military site	Arcueil	B	DGA
	Vaujours	C	CEA/DAM
Miscellaneous	Aubervilliers	A	Société Budin
	Marseille	A	Private address
	Marnaz	A	Private address
	Gruissan	C	INRA
	Vert-le-Petit (Le Bouchet-Ile verte)	C	CEA
	Opoul Périllos	C	Town hall
	Basse Ham	C	Établissements Wittman
	Orsay	A	Faculté d'Orsay

* Subdivision containing a set of lots, three of which remained to be cleaned up in late 2008.

foreign inventories of radioactive waste

6.1 UNITED KINGDOM



In the United Kingdom, a radioactive waste inventory is compiled every three years by the National Decommissioning Authority (NDA), in partnership with the Ministry of the Environment, Food and Rural Affairs. The 2007 UK radioactive waste inventory (published in 2008) is the latest applicable version.
This inventory presents the status of the radioactive waste in existence on 1 April 2007 and provides a list of all the waste to be produced in the UK (committed waste). It includes information on waste quantities, categories and characteristics. Forecasts are based on various assumptions regarding electricity production, decommissioning plans and other operations.
Excepting the storage of low- and intermediate-level, short-lived waste in the facility near Drigg (not far from Sellafield), no facility contains radioactive waste other than that produced by the facility itself.
The 2007 inventory covers 1,269 sites and includes defence activities. It takes into account actual or forecast waste mainly located near the production site and not yet subject to final disposal. In other words, this inventory only lists waste in storage or to be produced. It does not include the 800,000 m^3 of waste disposed of at the facility near Drigg.
The volumes listed in the inventory mainly correspond to the condition of the waste when inventoried, i.e. volumes occupied in reactor vessels (case of liquids to be treated), cells, silos, drums, etc.

6.2 SWITZERLAND

In a context of relatively modest nuclear activity, the first Swiss radioactive waste inventory was compiled in 1984 as part of the NAGRA radioactive waste disposal programme. Updated in 1994 and again in 2008, this inventory reflects the content of the MIRAM database, a radioactive waste inventory database created to meet the needs of waste management organisations. The inventory lists all materials considered as waste according to the Swiss classification, and therefore does not include VLLW or recoverable materials. It consists of a main report supplemented with 142 standard data sheets, each corresponding to a type of waste. All these documents are available to the general public on the NAGRA website (www.nagra.ch). There are plans to publish an updated version every two years.

6.3 BELGIUM

In March 2008, ONDRAF (Andra's Belgian counterpart) published its second five-yearly inventory, covering the period from 2003 to 2007. This inventory identifies 824 sites containing radioactive waste, decommissioning materials and nuclear materials. It provides a list of forecast waste volumes until 2070, the date by which all existing nuclear facilities will be dismantled. It includes non-nuclear sites containing radium-bearing ore processing waste (e.g. Olen plant), as well as facilities containing radioactive sources.
The inventory compiled in Belgium is intended to verify the availability of the financial resources necessary for waste producers to manage their waste. The goal is to prevent this waste from becoming a liability in case of lack or absence of said financial resources. The 2008 version places particular

emphasis on the methodological aspects of evaluating financial resources and the associated provisions.

The task of compiling an inventory of nuclear liabilities (entrusted to ONDRAF as per Article 9 of the Act of 12 December 1997) comprises the following steps:

- identifying the location and status of all nuclear facilities and all sites containing radioactive substances, with a radioactive substance defined as *"any substance containing one or more radionuclides whose activity or concentration cannot be disregarded as far as radiation protection is concerned"*;
- estimating the associated decommissioning and cleanup costs;
- evaluating the availability and sufficiency of financial provisions for funding ongoing or future operations;
- updating this inventory every five years.

The inventory is based on declarations submitted by the operators, who are responsible for all information transmitted to ONDRAF. The final report is not made public, since it contains operator-specific financial data considered by certain operators as commercially sensitive. A summary is available on the ONDRAF website (www.nirond.be).

6.4 GERMANY

In 2001, the German Parliament decided to implement a National Radioactive Waste Management Plan, including the preparation of waste status reports, waste treatment options and waste management solutions for different types of radioactive waste. Due to the premature end of the 15th legislature, the plan has not yet been implemented.

Since 1984, independently of the preparation of this National Radioactive Waste Management Plan (based on the National Radioactive Waste Inventory), the Federal Radiation Protection Agency (BfS) has developed a more systematic approach. BfS regularly collects and updates radioactive waste inventory data, including existing waste quantities and volumes, as well as forecasts for 2010 and 2080.

BfS conducts annual surveys with producers, by means of a questionnaire concerning the quantities and volumes of waste produced, treated and conditioned. This only concerns waste to be disposed of. The following are not included in the inventory: potentially releasable waste (as defined by German radiation protection regulations), depleted uranium, and recycled uranium and plutonium used to make fuel assemblies.

Inventory data concerning current and future waste production volumes is supplemented with chemical and toxicological data (organic and chemical composition).

Radioactive waste production forecasts are established by BfS in accordance with a scenario based on an agreement signed between the Federal Government and electricity producers in 2000 (limitation of reactor operating life, direct disposal of spent fuel).

The complete German National Radioactive Waste Inventory is not yet available to the public (not all aspects of its preparation are covered). This could be addressed by the future National Radioactive Waste Management Plan, along with other issues remaining to be resolved, such as what to do with exothermic waste.

6.5 SPAIN

ENRESA (Andra's Spanish counterpart) compiles and updates an inventory of radioactive waste produced in Spain, based on information supplied by waste producers. The first inventory studies were initiated in 1986, with the implementation of the 1st National Radioactive Waste Management Plan. Today, this information is compiled in a database used to produce a summary report. The latest version was published in January 2006 based on the database available on 31 December 2004.

The inventory is mainly intended to provide information on the volumes or quantities of waste produced and stored at each facility, as well as forecast data on all waste to be managed in Spain. Inventory data is classified by waste producer category. The inventory includes fuel assemblies, reactor waste and waste at the El Cabril disposal facility. It indicates volumes and quantities already produced and to be produced, as well as waste to be treated and disposed of abroad. Waste from former mining activities is also included in the inventory.

6.6 USA

Several radioactive waste inventory systems are used in the United States, varying according to waste type and origin, and depending on the relevant regulatory organisation, i.e. the Department of Energy (DOE) for public sector activities (including defence activities), and the Nuclear Regulatory Commission (NRC) for the private sector. Disposal sites are often determined by the origin of the waste.

The NRC compiles national inventories of spent fuel and sealed radioactive sources, mainly for non-proliferation and safety purposes.

For other waste categories, there is no single national inventory that pools information on all facilities and waste management organisations.

Radioactive waste is disposed of by both Federal Government agencies and private organisations. Eventually, disposal sites managed by the latter will be placed under the responsibility of State or Federal authorities.

Specifications regarding inventories depend on the State or Federal legislation applicable to each disposal site. The inventory must include a paper record of all waste, from the time it is produced and for as long as it remains at the disposal facility.

The NRC requires that waste producers in the private sector implement specific inventory systems for all waste at disposal sites.

For the public sector, the DOE (www.em.doe.gov) also has its own specific inventory systems, including the following:

- Solid Waste Information Tracking System (SWITS), used for solid waste, LILW and transuranic waste stored at the Hanford site;
- Integrated Waste Tracking System (IWTS), implemented in the Idaho National Laboratory;
- Waste Isolation Pilot Plant Waste Information Management System (WWIS).

Often more exhaustive than those compiled by foreign counterparts, these inventories list all activities generating radioactive waste and include mining waste, cleanup waste and hybrid low-level waste that is both radioactive and chemically toxic. This information can be freely accessed through databases available on the Internet.

In addition, the DOE prepares a summary of inventory data on nuclear facilities. This summary is included in the national report submitted to the International Atomic Energy Agency (IAEA) in accordance with the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

6.7 CANADA

Canada regularly publishes an inventory listing the location of radioactive waste, the current status of waste production, and the quantities of waste accumulated. It also provides forecast waste production quantities until the end of life of the current reactor fleet.

Radioactive waste is classified according to three categories corresponding to the different waste management policies implemented in Canada:
- nuclear fuel waste;
- low-level waste;
- uranium ore processing waste.

The first category concerns the fuel clusters of CANDU-type reactors. The second category concerns common waste resulting from the operation and dismantling of facilities and legacy waste resulting from past activities (e.g. Port Hope radium refinery). The third category concerns uranium processing waste in currently operating, inactive or decommissioned sites.
The inventory is compiled by the Low-Level Radioactive Waste Management Office (LLRWMO), which is also responsible for the implementation of current and legacy waste management programmes. The Office is administered by Atomic Energy of Canada Limited (AECL) on behalf of the Ministry of Natural Resources.
The inventory data is based on regulatory documents and reports and on information supplied by waste producers, waste holders and the National Safety Authority. It is presented in the form of a database.
Two inventories are currently available, published in 1999 and 2004. The next one is to be published in 2009.

6.8 INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA)

The IAEA is a United Nations agency that makes an international database called NEWMDB available to the public. This database is an inventory of radioactive waste in various countries. All data is updated on a regular basis and presentation formats tend to be standardised. Each member country generally uses its own radioactive waste classification system, which is converted according to a common classification system similar to that used in France. Waste volumes remain as indicated by each country: raw, treated, conditioned, stored or ready for disposal.
Every three years (most recently in 2008), member countries publish a national report under IAEA supervision, within the framework of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. A significant part of these reports is devoted to updating figures on existing radioactive waste and spent fuel inventories.

appendices

7

appendix 1

management of French and foreign radioactive waste resulting from spent fuel processing in AREVA facilities at La Hague

processing and recycling of foreign spent fuel at La Hague

Since it was commissioned in 1966, the UP2 plant at the La Hague site has processed approximately 5,000 tonnes of spent fuel from French GCRs (Chinon, Saint-Laurent-des-Eaux and Bugey nuclear power plants). The UP1 plant at the Marcoule site (commissioned in 1957) has processed similar types of fuel.

In the early 1970s, France decided to install a fleet of enriched-uranium light-water reactors. The UP2 plant was modified accordingly (HAO units in particular) and its capacity became sufficient to propose spent fuel processing services to foreign customers, with the first contracts signed in 1971. The UP3 and UP2-800 plants were commissioned in 1990 and 1994 respectively, and by late 2008 a total of 24,000 tonnes of LWR spent fuel had been processed for recycling at the La Hague site (approximately 58% for France, 23% for German customers, 12% for Japanese customers, and the rest for Belgian, Swiss and Dutch customers).

As of 1977, AREVA began to include in its contracts with foreign electric utilities a clause for returning conditioned waste resulting from spent fuel processed at the La Hague site.

512 tonnes of foreign spent fuel have been processed and recycled under contracts signed before 1977 (not including a return clause), i.e. 5% of the total quantity of foreign spent fuel recycled to date at the La Hague site (and 2% of the total quantity of LWR fuel recycled there).
In 1991, the French Parliament adopted measures prohibiting the definitive disposal of waste resulting from spent fuel processing in France [I].
Article L. 542-2 of the Environmental Code (Article 8 of the Act of 28 June 2006 [II]) defines the framework for processing foreign spent fuel and radioactive waste. Henceforth, for the purpose of transparency, the introduction in France of spent fuel or radioactive waste for subsequent processing is subject to the signature of intergovernmental agreements published in the Official Journal of the French Republic (which specifies forecast periods for the receipt and processing of these substances).
This article also requires that spent fuel processing facility operators submit a report (made public on the Internet) to the appropriate Ministers before 30 June each year (the first report was submitted in 2008), including an inventory of all spent fuel and radioactive waste received from abroad and all resulting processing waste.
Under the provisions of the Act of 28 June 2006 (codified in Articles L. 542-2 and L. 542-2-1 of the Environmental Code) and Decree 2008-209 of 3 March 2008 [III], AREVA has set up an inventory and shipment management system for waste resulting from the processing of foreign spent fuel in basic nuclear installations (INB) at La Hague, approved by the Order of 2 October 2008 [IV]. The EXPER system, as it is called, is intended to *ensure the distribution of processing waste according to two types (waste to be shipped abroad and waste requiring long-term management on French territory) and to allocate the correct share to each party concerned* [III]. The distribution principles set out in Implementing Decree 2008-209 are discussed in Section 3 of this appendix.

"The disposal, in France, of radioactive waste received from abroad or resulting from the processing of foreign spent fuel or radioactive waste is prohibited". Article L. 542-2 of the Environmental Code

"The introduction, in France, of foreign radioactive substances for subsequent processing shall only be authorised within the framework of intergovernmental agreements and on condition that no radioactive waste resulting from the processing of these substances is stored in France beyond a date stipulated in these agreements. Specifically, these agreements shall define forecast periods for the receipt and processing of these substances and, if applicable, possible prospects for subsequent use of radioactive materials separated during processing". Article L. 542-2-1 of the Environmental Code

[I] Act 91-1381 of 30 December 1991 regarding research on radioactive waste management (referred to as the Bataille Act).

[II] Act 2006-739 of 28 June 2006 on the sustainable management of radioactive materials and waste. The provisions of this Act have been codified in the Environmental Code.

[III] Decree 2008-209 of 3 March 2008 regarding applicable procedures for processing of foreign spent fuel and radioactive waste.

[IV] Act of 2 October 2008 on the approval of the inventory and shipment management system for waste resulting from the processing of foreign spent fuel in basic nuclear installations (INB) at La Hague.

conditioning
of final radioactive waste
from spent fuel processing

2

The spent fuel processing and recycling operations performed at the La Hague site consist in separating recoverable materials (uranium and plutonium) from the final radioactive waste containing most of the spent fuel activity. Recoverable materials are recycled into uranium- or plutonium-based fuel (MOX fuel) for subsequent use in nuclear power plant reactors. Final radioactive waste is conditioned in waste packages for storage and transport as per applicable safety requirements. This conditioning is also intended to ensure long life and effective long-term confinement with a view to subsequent management.

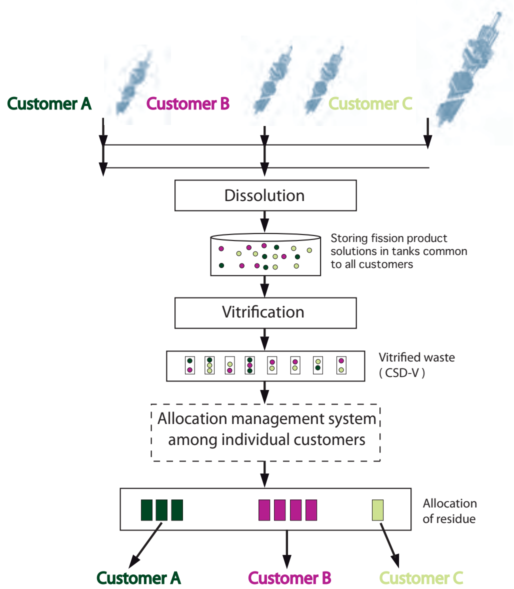
"The final radioactive waste contained in the spent fuel processed in the La Hague facilities is divided into two categories: fission products and cladding waste.

- *Fission products generated by in-reactor combustion are separated from recoverable materials at the La Hague facilities and subsequently calcinated and conditioned in a glass matrix. This glass is then poured into standard containers to form vitrified waste packages. As a result, nearly all the activity contained in the ultimate waste is conditioned in a compact, lasting and confined manner. All ultimate waste is classified as high-level waste (HLW).*
- *Cladding waste is composed of metallic components (cladding tubes, plates) used to secure and confine the fuel, including associated assembly parts (spacer grids, end caps). This waste is compacted and conditioned in standard containers at the La Hague facilities to form compacted waste packages. All cladding waste is classified as intermediate-level, long-lived waste (ILW-LL).*

Waste resulting from spent fuel processing is therefore shipped to foreign owners in these two types of waste package." [IV]

Fission products are conditioned in standard vitrified waste packages (CSD-V) and cladding waste is conditioned in standard compacted waste packages (CSD-C).

This continuous process does not allow AREVA to distinguish between material flows for different customers. On the other hand, the survey of incoming and outgoing radioactive substances allows individual customer follow-up. The diagram shown here illustrates the principle of waste package allocation in the specific case of pooled fission product management.



Waste package allocation to AREVA La Hague customers: specific case of vitrified waste packages

[IV] Order of 2 October 2008 on the approval of the inventory and shipment management system for waste resulting from the processing of foreign spent fuel in basic nuclear installations (INB) at La Hague.

allocation management system implemented at the La Hague site: EXPER

3

"All operators ensuring (or planning to ensure) the processing of spent fuel or radioactive waste originating from France or from abroad shall implement systems to manage the allocation of the resulting processing waste according to two types (waste to be shipped abroad and waste requiring long-term management on French territory) and to allocate the correct share to each party concerned."

Article 2 of Decree 2008-209 of 3 March 2008

As previously explained, AREVA has implemented the EXPER system within the framework of existing legal and regulatory provisions [II], [III] and [IV]. The Order of 2 October 2008 defines the system as follows: *"It is exclusively devoted to spent fuel processing. It serves the following purposes:*
a) managing the allocation of conditioned waste packages to customers;
b) monitoring completed and forecast schedules, from spent fuel receipt and processing to waste package shipment.

This system replaces the waste activity unit system (UR[1] system) implemented by AREVA in the early 1990s. In addition to the activity indicator used in the UR system, the EXPER system also includes a mass indicator." [IV]

3.1 Allocation principles

The EXPER system is based on the following principles for the allocation of waste resulting from spent fuel processing or received from abroad:

- incoming and outgoing radioactivity must be equal;
- the mass of incoming and outgoing radioactive substances must be equal.

These principles apply to waste to be inventoried for shipment.

This inventory system is used to assess the following:

- **activity** to be shipped to each owner, expressed in **waste activity units** and corresponding to the quantity of neodymium contained in the ultimate waste (neodynium is a fission product chosen because it is a good indicator of overall activity content and can be accurately measured);

[II] Act 2006-739 of 28 June 2006 on the sustainable management of radioactive materials and waste. The provisions of this Act have been codified in the Environmental Code.

[III] Decree 2008-209 of 3 March 2008 regarding applicable procedures for processing of foreign spent fuel and radioactive waste.

[IV] Order of 2 October 2008 on the approval of the inventory and shipment management system for waste resulting from the processing of foreign spent fuel in basic nuclear installations (INB) at La Hague.

1 Presented in Appendix 1 of the National Inventory issued in 2006.

- **mass** to be shipped, expressed in **waste mass units** and corresponding to the mass (in kg) of spent fuel metallic structures.

"These assessments are mainly performed for incoming spent fuel and outgoing waste packages." [IV]

Article 3 of the Decree of 3 March 2008 [III] specifies the following: *"all operators ensuring or planning to ensure the processing of spent fuel or radioactive waste received from abroad shall possess a system to monitor all incoming spent fuel and radioactive waste received from abroad and all outgoing radioactive waste to be shipped abroad. This system shall indicate waste quantities and physical characteristics according to origin. It shall maintain an inventory of processed waste and shall manage its allocation to recipients. It shall record dates on which waste is received in France, waste processing periods, and dates of waste shipment abroad. It shall be consistent with the conditions of application of each intergovernmental agreement."*

3.2 Waste package allocation

The EXPER system is used to manage the allocation of waste packages to customers.

"The identification of waste packages prior to shipment is referred to as waste package allocation. The principle consists in allocating waste packages to customers according to the activity and mass of incoming spent fuel. This allocation is performed before shipment. Prior to shipment, the customer is the owner (creditor) of the waste activity and waste mass units inventoried. The general rule is based on the interchangeability of waste packages within each category. According to this rule, every standard waste package generated in compliance with specifications approved by the customer is attributable to the latter. The correspondence between incoming and outgoing waste activity or waste mass units is stipulated at the end of the contract (...)." [IV]

3.3 Customer account management

The Order of 2 October 2008 [IV] stipulates the following: *"AREVA shall manage "accounts" for all customers of the La Hague processing plant, to which waste activity and waste mass units shall be allocated for each customer. These accounts shall be credited or debited during the various phases of spent fuel processing.*

A customer's account shall be credited with the corresponding number of waste activity and waste mass units by the beginning of spent fuel processing operations at the latest.

Upon shipment of waste packages (...), the corresponding number of waste activity and waste mass units shall be debited from the customer's account."

Inventory system audits

"The EXPER system is implemented via a set of management procedures defining the system's operation within the framework of the La Hague processing plant's quality control system. These management procedures are approved by relevant AREVA customers and used to establish their yearly inventories. Customers can appoint an organisation independent of the AREVA group to verify the correct implementation of these procedures and to certify their inventories every year. The correct application of these procedures is audited each year by a dedicated organisation operating on behalf of the Ministry for Energy."

Order of 2 October 2008 [IV]

[III] Decree 2008-209 of 3 March 2008 regarding applicable procedures for processing of foreign spent fuel and radioactive waste.

[IV] Order of 2 October 2008 on the approval of the inventory and shipment management system for waste resulting from the processing of foreign spent fuel in basic nuclear installations (INB) at La Hague.

Shipment

to foreign customers

4

4.1 Waste covered in Article L. 542-2-1 of the Environmental Code

In the case of the La Hague facilities, this concerns spent fuel processing waste conditioned in standard vitrified waste packages (CSD-V) and standard compacted waste packages (CSD-C).
In compliance with the Order of 2 October 2008 [IV], CSD-V and CSD-C packages are respectively shipped in accordance with the activity and mass of imported spent fuel.

CSD-V package (left) and CSD-C package (right)

Return of vitrified waste to Japan

Standard vitrified waste packages (CSD-V)

CSD-V packages began to be shipped to foreign customers in 1995. Most of the activity contained in spent fuel is conditioned in these packages. According to the estimates as at 31 December 2007 shown in Table 1, the vast majority of CSD-V packages produced or to be produced concerns France, since 79% of the activity contained in foreign spent fuel was shipped prior to that date. In particular, it should be noted that CSD-V shipments to Japan and Belgium have already been completed.

TN28 cask used to transport CSD-V packages to Belgium, the Netherlands and Japan

CSD-V packages delivered to foreign customers are currently stored:

- in shafts built in facilities similar to those at La Hague (Rokkasho-Mura in Japan, Mol in Belgium, HABOG in the Netherlands, ATC project in Spain);
- in transport and storage casks (Gorleben in Germany, Zwilag in Switzerland).

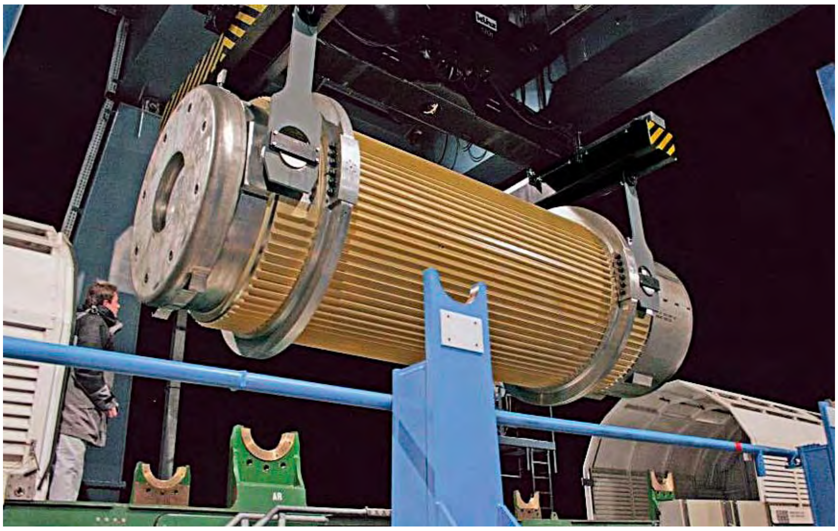
HABOG high-level vitrified waste storage facility (Hoogradioactief Afval Behandelings en Opslag Gebouw) in the Netherlands

Standard compacted waste packages (CSD-S)

The first CSD-C packages are scheduled for shipment in 2009. Estimated shares corresponding to French owners and foreign customers are shown in Table 1.

There are more CSD-C packages remaining to be shipped than CSD-V packages, since AREVA has given priority to the shipment of activity units, rather than mass units.

Cross-section of a CSD-C package



TN81 cask used to transport CSD-C packages

Table 1: Estimated share of CSD-V and CSD-C packages corresponding to each country as at 31 December 2007

	Total number of packages in storage	Estimated total number of packages to be produced from unconditioned waste in storage	Total quantity of packages produced or to be produced from waste in storage		Estimated share of waste resulting from spent fuel processing prior to 31/12/07 corresponding to French owners (%)	Estimated share of waste resulting from spent fuel processing prior to 31/12/07 corresponding to foreign owners (%)							
			Number of packages	Volume (m^3)		Germany	Australia	Belgium	Spain	Italy	Japan	Netherlands	Switzerland
CSD-V	9,088	603	9,691	1,696	87.7	9.3	< 0.01	0	0.7	0	0	0.1	2.2
CSD-C	6,089	8,186	14,275	2,612	50.9	28	0	3	0	0	12.9	1.5	3.7

This table lists the following, in compliance with applicable regulations:

- Quantities of CSD-V and CSD-C packages already produced and placed in storage, and quantities to be produced from unconditioned waste in storage as at 31 December 2007;
- Estimated share of CSD-V and CSD-C packages corresponding to France and to each foreign customer country (radioactive waste covered in Article L. 542-2-1 of the Environmental Code), expressed as a percentage of the total number of packages produced or to be produced from waste in storage as at 31 December 2007.

Note:

The estimated total number of packages to be produced from unconditioned waste in interim storage as at 31 December 2007 concerns spent fuel already sheared on that date. As at 31 December 2007, the spent fuel pits in the La Hague site contained 6.2 tML of unsheared spent fuel received from Italy in 2007, for which AREVA is to ship six CSD-V packages and six CSD-C packages.

4.2 Other types of radioactive waste

Although the types of waste referred to in this section are not covered in Article L. 542-2-1, it is worth mentioning them all the same.

Certain contracts include the right for AREVA to ship waste packages of types other than those described above. This particularly concerns bituminised waste drums (radioelements embedded in bitumen), CSD-B packages (radioelements embedded within a vitrified matrix) and C5 canisters

(radioelements embedded in an inert material). These types of package ensure the confinement of certain process radionuclide flows.
These radionuclides are currently transferred directly to a vitrification facility. However, part of the waste produced is still stored in raw form (in silos or tanks) and falls within the scope of programmes currently being implemented to recover and condition legacy waste. The volumes indicated in Table 2 correspond to the current shipment scenario.

Table 2: Estimated share of other types of waste package (bituminised waste drums, CSD-B packages, C5 canisters) corresponding to French producers on 31 December 2007

	Total number of packages in storage	Estimated total number of packages to be produced from unconditioned waste in storage	Total volume of packages produced or to be produced from waste in storage (m^3)	Estimated share of volume corresponding to French owners (%)
CSD-B	0	381	7,942	93.2
Bituminised waste drums	10,912	0		
C5 canisters	0	20,300		

This table shows the quantities the other types of waste package concerned by current AREVA shipment scenarios. As in the previous table, the quantities indicated correspond to packages already produced or to be produced (case of new CSD-B packages and C5 canisters).

In addition, a contract concerning an old Generation 1 GCR includes clauses providing for the shipment of cemented waste. This currently amounts to 177 cemented waste drums to be shipped. However, CSD-C packages may eventually be used.

appendix 2 committed waste

The National Inventory does not set out to give guidelines on energy policy. That responsibility lies with the public authorities. Nonetheless, the decision was made that this National Inventory - like the 2006 edition - should estimate the potential volumes of waste produced by all existing facilities up to the end of their life according to two basic scenarios. This is referred to as "committed waste". Forecast values are estimated by Andra using data provided by waste producers for the current year and based on assumptions that could change in future inventories.

As indicated in Chapter 3, two scenarios are considered in the National Inventory for the current year:

- Scenario 1: nuclear power production will continue and all fuel will be processed, apart from certain types of civil fuel, e.g. EL4 heavy-water reactor fuel (Brennilis site), Osiris research reactor fuel, various types of experimental fuel, Generation 1 GCR fuel currently not processed. This is the scenario on which the National Inventory bases its forecasts of waste volumes as at the end of 2020 and 2030 (see Subchapter 3.2);
- Scenario 2: nuclear power production will be discontinued, leading to the end of fuel processing operations and to the direct disposal of the remaining spent fuel. As indicated in Chapter 3, this scenario is not industrially realistic at the present time. It is purely illustrative.

Note that these two scenarios are based in particular on the following assumptions:

- total of 59 "committed" reactors (58 PWRs currently in operation, and one EPR in operation as of 2013);
- identical operating life for all reactors (40 years);
- recycling of spent fuel processing waste provides sufficient enriched, recycled uranium to power 4 reactors and sufficient MOX fuel to power 22 reactors.

The waste volume forecasts up to 2030 (as per scenario 1) and the volumes of dismantling waste anticipated after this date have already been described in detail in this report (particularly in Chapter 3).

As indicated in Chapter 3, according to scenario1, nuclear power production will stabilise at 430 TWh net per year (+ 13 TWh per year as of 2013, taking into account the Flamanville EPR). This assumes the gradual replacement of the current reactor fleet with a new reactor fleet with similar fuel operating conditions. This new reactor fleet consumes materials not recycled in the first fleet, but the waste produced is not inventoried as it was considered as non-committed waste at the end of 2007.

In scenario 2, nuclear power production will decrease as of 2017 (decommissioning of the first 900 MW unit), with discontinuation of plutonium separation. Fuel processing will be discontinued in 2019, with (i) sufficient plutonium available to power MOX reactors until the end of their operating lives and (ii) unprocessed spent fuel considered as waste.

Scenario 1: nuclear power production continues

Waste resulting from the operation and dismantling of nuclear reactors and fuel cycle front-end and back-end fuel facilities

Scenario 1 considers the waste flows to be generated beyond 2030 for each additional year of operation of nuclear facilities still operating on that date.

Beyond 2030, there will remain approximately 18,000 tonnes of fuel to be processed (MOX fuel and enriched recycled uranium mixed with UOX fuel), resulting in the production of 2,850 m^3 of high-level vitrified waste (production ratio of 0.90 CSD-V waste packages per tonne) and 2,900 m^3 intermediate-level, long-lived compacted cladding waste (0.85 CSD-C waste packages per tonne).

This scenario also anticipates the following (excluding dismantling):

- ILW-LL: 260 m³ from PWRs still in operation and 850 m³ from fuel cycle back-end activities (operation of spent fuel processing facilities);
- LILW-SL: 4,600 m³ from PWR operation and maintenance, 1,000 m³ from fuel cycle front-end (fuel fabrication) and 12,000 m³ from fuel cycle back-end activities (spent fuel processing);
- VLLW: 3,000 m³ from reactor operation and maintenance, 16,000 m³ from fuel cycle front-end activities and 10,000 m³ from fuel cycle back -end activities.

In 2030, the dismantling of first generation EDF nuclear power plants will not yet be completed. Nevertheless, it is assumed that GCR graphite stacks and reflectors will have been dismantled. As a result, all LLW-LL from EDF reactors is already accounted for prior to 2030. It is also assumed (see Chapter 3) that the dismantling of current PWR plants will only begin after 2030 and will generate 6,000 m³ of ILW-LL, 250,000 m³ of LILW-SL and 470,000 m³ of VLLW.

The dismantling of the UP2-800 and UP3 plants at the La Hague site and the Melox plant at the Marcoule site[1] will also begin after 2030. AREVA estimates that these operations will generate 3,000 m³ of ILW-LL, 23,200 m³ of LILW-SL and 30,500 m³ of VLLW[2].

For the dismantling of fuel cycle back-end facilities, AREVA anticipates 5,000 m³ of LILW-SL and 4,000 m³ of VLLW.

Operating and dismantling waste generated by other activities

The main activities other than nuclear power production which generate HLW and ILW-LL are those conducted by the CEA's Civil Research Division (CEA Civil) and Military Applications Division (CEA/DAM). The date of discontinuation of these activities is conventionally set as 2040.

The HLW resulting from the processing of fuel used in these activities amounts to a few m³ per year, which is negligible in comparison with that generated by nuclear power production. The ILW-LL generated by these activities (excluding dismantling) is estimated at approximately 50 m³ per year, i.e. 550 m³ from 2030 to 2040.

In addition, as an initial estimate, it can be assumed that CEA Civil and CEA/DAM research activities (excluding dismantling) will also generate 2,000 m³ of LILW-SL per year (i.e. 22,000 m³ from 2030 to 2040) and 2,000 m³ of VLLW per year (i.e. 22,000 m³ from 2030 to 2040).

The dismantling after 2030 of facilities under the responsibility of CEA Civil (including the UP1 plant and G1 reactor at the Marcoule site) should generate approximately 750 m³ of ILW-LL, 5,700 m³ of LLW-LL, 32,000 m³ of LILW-SL and 115,000 m³ of VLLW.

The dismantling after 2030 of facilities under the responsibility of CEA/DAM (including the UP1 plant and G2 reactor at the Marcoule site) should generate approximately 6,000 m³ of LLW-LL, 6,000 m³ of LILW-SL and 20,000 m³ of VLLW.

1 Dismantling waste generated by the UP1 plant is not included in this estimate. It is accounted for in the estimate for CEA Civil Research Division facilities (CEA Civil).

2 LILW-SL and VLLW quantities have been estimated in tonnes by AREVA. The volumes indicated are based on a ratio defined by Andra.

It can also be assumed that chemical industries using naturally radioactive materials will continue to generate 100 m^3 of LLW-LL per year until the date conventionally set as 2040.

According to current estimates, the dismantling of CSFMA disposal facilities at the Aube site should also generate approximately 200 m^3 of LILW-SL and 340 m^3 of VLLW.

In addition, medical activities, conventional industrial activities, non-CEA research activities and national defence activities (DGA, SSA, Armed Forces, Gendarmerie) should also continue to generate radioactive waste beyond 2030. The implementation of initiatives to reduce the use of radioactivity in the medical and industrial sectors should nevertheless be noted. For example, the Smoke Detector Manufacturers Organisation (GESI) has undertaken to replace americium detectors with non-radioactive devices. Forecasts beyond 2030 are therefore particularly uncertain for these activities. They can be conventionally based on the assumption that current waste-generating activities will continue (producing mostly LILW-SL, in negligible quantities as compared to other activities mentioned earlier).
Adding the above values to those of the assessment for the end of 2030 (see Chapter 3) yields the following committed waste volumes for scenario 1:

Scenario 1 (nuclear power production continues): Waste volumes produced and to be produced (including dismantling), expressed in m^3 conditioned equivalent

HLW (vitrified waste)	7,910 (including 74 cubic metres of spent fuel)
ILW-LL	65,300
LLW-LL	164,700
LILW-SL	1,530,200
VLLW	1,560,200

Note:

The values listed above are rounded off to the nearest 10 m^3 for HLW, and to the nearest 100 m^3 for ILW-LL, LLW-LL, LILW-SL and VLLW.

Scenario 2: nuclear power production is discontinued

As indicated in Chapter 3, the assumption of a predicted lifetime of 40 years for all reactors leads to the decommissioning of existing reactors capable of converting plutonium to MOX fuel, starting in approximately 2020 and ending in approximately 2030. The amount of plutonium required to fuel today's 22 MOXable reactor units until the end of their life can be calculated on the basis of their decommissioning schedule. After deducting plutonium stocks existing at the end of 2007 and allowing for the quantities expected from future processing, based on a rate of 850 tonnes of UOX fuel per year, processing operations should be brought to a definitive halt in 2019, according to an EDF calculation. This date should ensure that the stock of separated plutonium (i.e. excluding the plutonium contained in spent fuel[3]) has been completely eliminated by the time the last MOXed reactor shuts down in 2030.
As a result, all spent fuel not processed on that date would be considered as waste. At the end of life of the reactor fleet, the total quantity of high-level spent fuel waste would therefore amount to 27,950 tonnes, i.e. 27,350 tonnes of PWR spent fuel (including 2,900 tonnes of MOX fuel), 420 tonnes of EPR spent fuel and 180 tonnes of fast breeder reactor spent fuel (SUPERPHENIX). In addition, in 2019 (date of discontinuation of spent fuel processing), the the stock of depleted uranium should approach the stock forecast for the end of 2020 (see Subchapter 3.2), i.e. approximately 332,000 tonnes.

As of 2019, processing facilities would only generate dismantling waste. On the other hand, fuel cycle front-end facilities and EDF reactors still operating would continue to generate LILW-SL and VLLW (as well as small quantities of ILW-LL) until 2052, when the last reactor unit to be commissioned (Flamanville EPR) will be shut down. Regarding CEA Civil and CEA/DAM activities, their impact on facilities concerned by the discontinuation of spent fuel processing in 2019 is considered as negligible. As a result, the decommissioning date for these facilities is conventionally set as 2040 (as in scenario 1).

3 This includes SUPERPHENIX fast breeder reactor fuel not yet processed, with a plutonium content (equivalent to 1.5 years of UOX processing) considered as a mobilisable resource in the previous National Inventory, which explains the date of 2017.

Waste resulting from the operation and dismantling of nuclear reactors and fuel cycle front-end and back-end facilities

Considering the number of reactors that will still be operating in 2020 (51), the quantities of waste generated up to late 2019 (excluding dismantling) can be estimated by subtracting the following quantities (corresponding to waste production forecasts for the year 2020) from the values of the assessment as at the end of 2020:

- HLW: 110 m^3, assuming a processing flow of 850 tonnes of UOX per year and a conditioning ratio of 0.74 CSD-V packages per tonne of processed fuel;
- ILW-LL: 30 m^3 from PWR operation and maintenance and 155 m^3 from fuel cycle back end activities[4];
- LILW-SL: 3,600 m^3 from PWR operation and maintenance, 100 m^3 from front end (fuel fabrication) and 1,200 m^3 from fuel cycle back-end activities (spent fuel processing);
- VLLW: 2,300 m^3 from PWR operation and maintenance, 1,600 m^3 from fuel cycle front-end activities and 1,000 m^3 from spent fuel processing.

In addition, the *pro rata* waste production corresponding to the number of reactors still operating from 2020 to 2052 (gradual decrease to zero until 2052, date of decommissioning of Flamanville EPR reactor) would also need to be considered, i.e.:

- 430 m^3 of ILW-LL, 25,000 m^3 of LILW-SL and 16,100 m^3 of VLLW from EDF nuclear power plants;
- 565 m^3 of LILW-SL and 9,133 m^3 of VLLW from fuel cycle front-end activities[5].

Finally, the dismantling waste generated after 2020 would also need to be considered, i.e.:

Nuclear power plants:
- 6,700 m^3 of ILW-LL
- 17,000 m^3 of LLW-LL
- 290,000 m^3 of LILW-SL
- 505,500 m^3 of VLLW

Fuel cycle front-end facilities:
- 5,000 m^3 of LILW-SL
- 83,400 m^3 of VLLW

Fuel cycle back-end facilities:
- 3,400 m^3 of ILW-LL
- 28,000 m^3 of LILW-SL
- 36,400 m^3 of VLLW

4 133 m^3 correspond to compacted waste packages resulting from the processing of 850 tonnes of ILW-LL (0.85 CSD-C packages per tonne). The remaining 22 m^3 include 12 m^3 of cemented waste and 10 m^3 of alpha-emitting technological waste from processing. Processing flows are based on AREVA forecasts, the objective being to reduce waste volumes by increasing the proportion of compacted waste. In addition, the volume of effluent treatment waste is considered as negligible (bituminised sludge packages).

5 Volumes estimated by Andra on the basis of current flow values indicated by AREVA. Fuel cycle front-end waste generated by EPR fuel fabrication activities is not considered (marginal quantity).

Operating and dismantling waste generated by other activities

Beyond 2030 and up to 2040 (the date conventionally set for the decommissioning of all CEA Civil and CEA/DAM facilities), the waste generated by CEA Civil and CEA/DAM activities, based on the current waste production rate (excluding dismantling), will amount to approximately 200 m^3 of ILW-LL, 5,000 m^3 of LILW-SL and 10,000 m^3 of VLLW. The dismantling waste generated after 2030 (indicated in Chapters 3 and 4) would also need to be considered.

As in scenario 1, it can also be assumed that chemical industries using naturally radioactive materials will continue to generate 100 m^3 of LLW-LL per year until the date conventionally set as 2040.

As in scenario 1, according to current estimates, the dismantling of CSFMA disposal facilities at the Aube site should generate approximately 200 m^3 of LILW-SL and 340 m^3 of VLLW.

In the case of other facilities (research facilities, military facilities, hospitals, laboratories, conventional industries), it is not possible to set a single decommissioning date or to assess individual schedules. The assumption adopted in scenario 1 is therefore maintained, i.e. continuation of current practices generating waste (mostly LILW-SL, in negligible quantities as compared to other activities mentioned earlier).

The committed waste volumes for scenario 2 are therefore calculated as follows:

- by subtracting the estimated waste quantities generated by reactor operation and maintenance activities and fuel cycle front-end and back-end activities for the year 2020 from the estimated values as at the end of 2020;
- by adding the waste production forecast up to the end 2019 to the waste generated by reactor operation and fuel cycle front-end activities from 2020 to 2052 according to this scenario;
- by adding the dismantling waste generated by EDF reactors and fuel cycle front and back-end facilities after 2020 to the estimated values as at the end of 2020;
- by adding the operating waste generated by other activities (including CEA Civil and CEA/DAM activities) between 2030 and 2040, as well as the dismantling waste generated by these activities after 2030, to the estimated values as at the end of 2030.

Scenario 2 (nuclear power production is discontinued): Waste volumes produced and to be produced (including dismantling), expressed in m³ conditioned equivalent	
HLW (spent fuel) **HLW (vitrified waste)**	89,000[6] (28,000 tonnes) 3,500
ILW-LL	58,900
LLW-LL	164,700
LILW-SL	1,466,500
VLLW	1,500,300

Note:

The values listed above are rounded off to the nearest 10 m^3 for vitrified HLW, to within 100 m^3 for ILW-LL, LLW-LL, LILW-SL and VLLW, and to the nearest 1,000 m^3 for spent fuel.

6 Based on the assumptions regarding PWR spent fuel conditioning considered by Andra in the 2005 geological disposal feasibility report. It is assumed that SUPERPHENIX fast breeder reactor fuel assemblies (approximately 1,000) are conditioned as MOX fuel.

appendix 3 radioactive waste management solutions

The French National Radioactive Materials and Waste Management Plan (PNGMDR) describes the management solutions for the different categories of radioactive waste (see Chapter 1). These management solutions consist of four types of disposal facility: two are currently operational and the other two are being studied. The receipt of waste in one of the two existing types of disposal facility is considered on the basis of a short-, medium- and long-term safety assessment.

CSTFA disposal facility

The very-low-level waste disposal facility (CSTFA) has been operated by Andra since the summer of 2004. This facility has "installation classified for environmental protection" status (ICPE) and was licensed for operation by Order 03-2176 A of 26 June 2003.

The facility covers an area of 45 hectares and is located for the most part within the municipal boundaries of Morvilliers. It is designed to accommodate 650,000 m^3 of waste, mainly from the dismantling of decommissioned French nuclear facilities. Waste packages are inspected upon arrival and deposited in cells excavated in clay, the base of which is engineered to collect seepage water. They are isolated from the environment by:

- a synthetic membrane surrounding the waste and linked to a monitoring system;
- a thick layer of clay underneath and on the sides of the disposal cells;
- a clay cover placed over the waste.

During use, the cells are protected by tunnel-shaped removable covers and equipped with monitoring devices.

CSTFA disposal facility

CSFMA disposal facility

The low- and intermediate-level waste disposal facility (CSFMA) is located in the municipality of Soulaines-Dhuys and has been operated by Andra since 1992. It is a basic nuclear installation (INB).

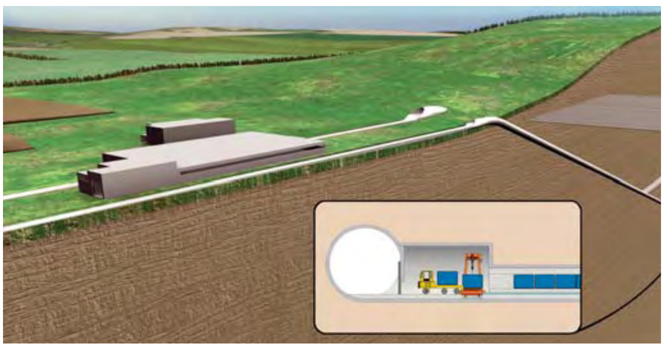
Waste packages are placed in reinforced concrete disposal cells 25 metres square and 8 metres high. While a cell is being filled, packages are protected from rain by movable roofs. Once a cell is filled, it is sealed by a concrete slab and covered with a leaktight polyurethane layer. The impermeability of the cells is verified via a network of underground drifts inspected on a regular basis. The various cells and drifts form a seismic-resistant structure.
Disposal cells are built on an impermeable clay layer which acts as a natural barrier in the event of accidental dispersal of radioactive elements to the groundwater. Above the clay, a sandy layer drains rainwater to a single outlet to simplify environmental monitoring.

CSFMA disposal facility

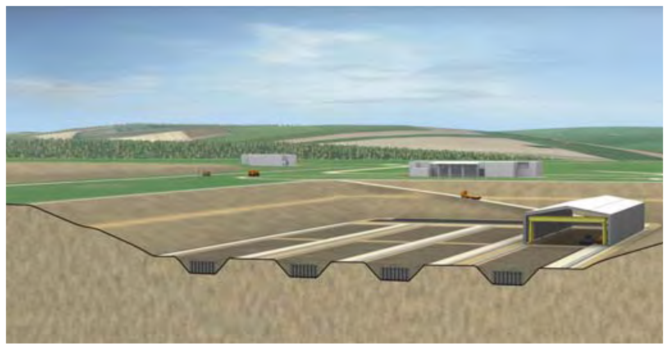
Near-surface repository project

Protramme Act 2006-739 of 28 June 2006 entrusts Andra with the task of developing near-surface disposal solutions for graphite waste (generated by the dismantling of Generation 1 GCRs) and radium-bearing waste. Andra has also been asked to consider whether these solutions would be compatible with the handling of other types of low-level, long-lived waste, in particular spent sealed sources and low-level radioactive objects containing radium, thorium and uranium.
The near-surface repository concept is intended to limit water circulation, minimise the release of radionuclides from waste packages, physically immobilise radionuclides within the repository, delay and attenuate radionuclide migration to the environment and isolate waste packages from human activities and natural phenomena. After closure of the repository, these safety functions will be ensured passively with no need for human intervention.
The repository is to be built in a clay layer. Two design options are currently being considered, both based on techniques for the construction of near-surface structures. The first option consists in using open-cut excavation in techniques to access the repository. Once the waste has been deposited, the repository zone is backfilled with broken rock from the site. This "disturbed cover" design is applicable to radium-bearing waste and allows a repository depth of approximately 30 metres. The second option involves the use of subsurface excavation techniques, with access to the repository via access drifts that are backfilled after waste has been disposed of. This "undisturbed cover" design is suitable for both types of waste and allows greater repository depths (50 to 200 metres).

The identification of a suitable site for a near-surface repository requires the cooperation of the municipal authorities of areas where the subsurface contains a potentially favourable clay layer. The call for expressions of interest from such municipalities ended on 31 October 2008. Based on these results, in late 2008 Andra proposed several target areas for geological surveys to be conducted from 2009 to 2010. The site will be selected after completion of geological surveys, confirmation of applications by interested municipalities and local consultation.
From a safety perspective, all this work is based on the general guidelines for the identification of a suitable LLW-LL repository site, published by the Nuclear Safety Authority (ASN) on 5 May 2008.
The site identification phase will be followed by the preparation of the detailed design report and construction licence application. The dimensioning inventory model will be completed in 2010. The construction licence will include draft versions of waste package acceptance requirements. Commissioning of the near-surface repository can be expected for 2019.



Near-surface repository with undisturbed cover



Near-surface repository with disturbed cover

Deep repository project

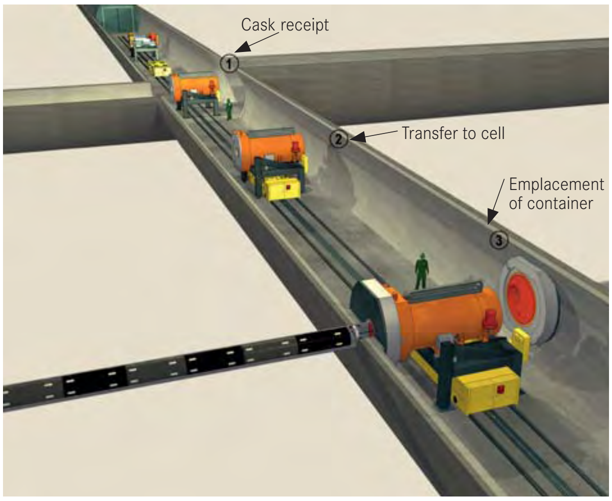
Planning Act 2006-739 of 28 June 2006 entrusts Andra with the task of conducting studies and research for the selection and design of a deep repository site. This repository will receive radioactive waste that cannot be disposed of at surface or near-surface repositories for reasons of safety or radiological protection, i.e. HLW and ILW-LL. Commissioning is scheduled for 2025, subject to licensing requirements. The Act stipulates that the repository should be consistent with the principle of reversible disposal for at least 100 years. Reversibility conditions will be set out in a future Act, based on the results of studies and research conducted up to 2014.
Underground disposal facilities will be constructed in the Callovo-Oxfordian argillite formation currently studied by the Meuse/Haute-Marne Underground Research Laboratory.
A region of interest of approximately 30 km^2 suitable for the construction of underground disposal facilities will be identified in 2009 within the transposition zone around the laboratory (250 km^2 straddling the Meuse-Haute-Marne boundary). An in-depth geological survey of the region of interest will then be conducted from 2010 to 2012. During this period, several construction scenarios for underground and surface facilities will be considered in order to prepare the public consultation regarding the project (in 2013), on the basis of which the choice of site will then be made.

The report submitted by Andra to the French Government in 2005 describes the architecture of such a repository at the feasibility design stage. Technical concept optimisation work is currently in progress. In 2009, Andra will propose a set of safety and reversibility options that will be used to complete basic design work and prepare the construction licence application (to be submitted by the end of 2014). The dimensioning inventory model will be presented in 2009. As in the case of the near-surface repository project, the construction licence application will include draft versions of waste package acceptance requirements.

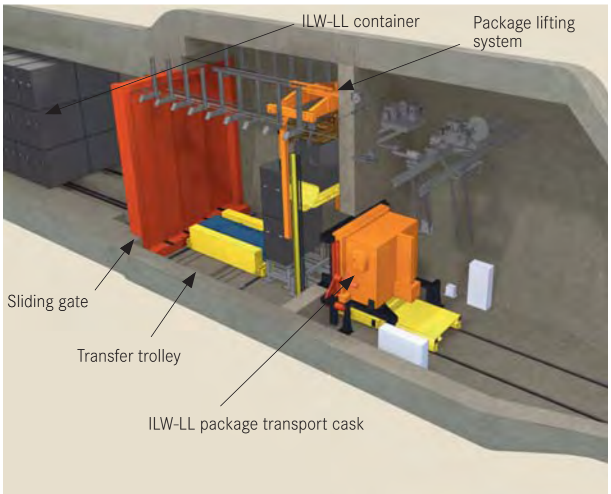
The waste packages will consist of primary waste packages and containers like those currently generated by waste producers. The packages will be placed in underground disposal cells excavated in the argillite and in accordance with the reversibility principle. The architecture considered comprises disposal cells for different waste categories within specific repository zones. ILW-LL and HLW repository zones will therefore be physically separated from one another.

HLW contains most of the activity content of radioactive waste and is characterised by high heat release (up to 500 W per waste package at the time of disposal, which will only take place after a thermal decay storage period of at least 60 years for vitrified waste packages currently produced by the La Hague plant). The disposal density of HLW packages (number of packages per disposal cell, distance between cells) must therefore be limited so that the temperature level remains compatible with repository safety functions. The low or negligible heat release of ILW-LL allows more compact disposal. The total volume of ILW-LL packages is much greater than for HLW packages.

After closure of the repository (backfilling and sealing of access drifts and shafts), human health and environmental protection will rely on passive safety functions, as for the near-surface repository. The safety aspects of this project are based on the safety guidelines for the final disposal of radioactive waste in a deep geological formation, published by the Nuclear Safety Authority (ASN) on 21 March 2008.



Deep HLW disposal



Deep ILW-LL disposal

appendix 4

storage requirements for HLW and ILW-LL packages

1 storage requirements on waste-producing sites prior to deep repository commissioning, scheduled for 2025

Storage requirements on waste-producing sites are assessed by comparing HLW and ILW-LL production forecasts up to 2030 with the storage capacity that can be made available at that time. The commissioning of the deep repository, scheduled for 2025, will be followed by a gradual "run-in" period. This assessment is therefore based on the conservative assumption that the existence of the repository will not have any significant impact on production site storage capacity before 2030.

1.1 Storage requirements mainly connected with the operation of La Hague plants

Standard vitrified waste packages (CSD-V) are transferred to three storage facilities: R7, T7 and E-EV-SE, which have a total capacity of 2,174 m^3. This is expected to be saturated by 2012. In 2007, AREVA therefore initiated studies for the construction of an extension to the E-EV-SE facility. The extension will be operational by 2012 and increase the capacity to 2,911 m^3. A second extension with similar capacity is also planned by AREVA for 2017, bringing the capacity to 3,648 m^3. With overall production predicted to reach 4,470 m^3 by 2030, a third extension will probably be required by around 2022.

Compacted hulls and end caps are stored at the Compacted Hull Storage Facility (ECC), which has a capacity of 3,806 m^3. Production forecasts for 2030 (4,645 m^3) indicate that the facility will be saturated by then. The extension planned by AREVA for 2022 should meet these storage requirements.

Storage capacity is used to accommodate waste packages produced to date (cemented hulls and end caps and cemented operating waste conditioned in CAC asbestos-cement casks), currently being produced (solid operating waste conditioned in CBF-C'2 fibre-reinforced concrete containers and other waste packages intended for the CSFMA disposal facility (Aube)) and to be produced in the future (cemented pulverulent waste conditioned in 1.5 m^3 stainless steel drums).

In 2030, total storage capacity of 14,331 m^3 will still be available for these waste packages at the EDS/ADT2, EDS/EDT and EDS/EDC storage facilities, which should continue operating until 2040. Given the small volume of LILW-SL waste packages in transit (a few hundred m^3), this capacity seems sufficient to accommodate the overall production of 11,124 m^3 forecast for 2030.

Bituminised sludge packages produced by the STE3 effluent treatment facility are stored in building S, which, with a capacity of 4,760 m^3, will be able to handle the anticipated volumes up to 2030. The capacity provided by the extension of building ES (6,426 m^3) will be sufficient for storing sludge packages generated by the alternative bituminisation process, as well alpha-emitting contaminated waste packages, some of which come from the MELOX plant (Marcoule). These conditioning techniques are currently being investigated. According to the assumptions considered in this National Inventory, current and future waste production should amount to 9,533 m^3.

1.2 Storage requirements for waste packages connected with the dismantling of Marcoule facilities and with the recovery and conditioning of legacy waste

Vitrified waste packages produced to date at the Marcoule vitrification plant (AVM) and PIVER experimental vitrification facility, amounting to a total of 583 m^3, are currently stored at these facilities and could eventually be grouped together at the AVM storage facility, which has a storage capacity of 665 m^3. There is also enough capacity to store vitrified waste packages from the ATALANTE facility and vitrified washwater effluent packages and solid operating waste packages from the AVM facility, which should represent a total volume of 78 m^3 in 2030.

EIP drums (380-litre stainless steel drums used to recondition old bituminised sludge drums (7,000 out of a total of 26,131) are or will be stored at the Multipurpose Storage Facility (EIP facility). By 2030, the EIP facility could also be used to store cladding waste, metallic technological waste and process waste also conditioned in EIP drums. Its current capacity of 4,235 m^3 seems just enough to accommodate all such waste up to 2030, which should amount to 4,223 m^3.

In order to store the remaining old bituminised sludge drums (19,131 drums), an alternative to the construction of an extension to the EIP facility is currently being considered. This would involve placing the drums directly in containers modelled on the concrete container prototype developed by Andra. A storage facility for waste pending shipment for disposal (IAE facility) could also be built to store these containers, along with waste packages resulting from the recovery and reconditioning of old magnesium structural waste, the volume of which will reach 1,642 m^3 by 2030.

The bituminised sludge packages produced since October 1996 by the effluent treatment facility at the Marcoule site (STEL facility), those to be produced up to 2013, and the cemented sludge packages to be produced thereafter, will amount to a total volume of 518 m^3 as at the end of 2030. These packages are or will be stored in bunker 14 of the STEL facility, which has a storage capacity of 1,200 m^3.

1.3 Storage requirements in connection with the operation and dismantling of CEA facilities

+ HLW and ILW-LL packages: storage facilities at waste-producing sites should be capable of meeting currently anticipated storage capacity and duration requirements, as of 2015 (provided the necessary extensions are built).

Experimental spent fuels or those removed from CEA research reactors will eventually be stored at the CASCAD storage facility.

Filtration sludge packages cemented in 500-litre concrete containers and solid operating waste packages cemented in 870-litre drums are "slightly irradiating" waste packages. They will represent a total volume of 8,343 m^3 by 2030 and will need to be stored at the CEDRA storage facility for "slightly irradiating" waste. The capacity of this facility is to be increased from 450 m3 today to 8,800 m^3 in 2014.

"Medium irradiating" waste packages conditioned in 500-litre steel drums will occupy a total of 1,595 m^3 in 2030. This volume will be accommodated at the CEDRA storage facility, the capacity of which is to be increased from 825 m^3 to 2,350 m^3 in 2014.

The total volume of solid waste packages produced to date, conditioned in 1,800 or 1,000 litre concrete packages and immobilised in a cement or cement-bitumen matrix amounts to 695 m^3. These waste packages are currently stored at INB 56 and will eventually be transferred to a CEDRA facility scheduled for construction prior to 2014 with a capacity of 1,200 m^3. The same facility will be used to store the total volume of radium-bearing lead sulphate packages and source block packages produced to date (582 m^3), which could be shipped to the LLW-LL disposal facility before 20301[1].

1.4 Storage requirements in connection with the operation and dismantling of EDF reactors

The radioactive waste to be generated by the dismantling of the six GCRs, the Brennilis HWR, the Chooz A LWR and the SUPERPHENIX fast breeder reactor, and the used reactor internals from PWR operation (cemented in C1PG containers), will amount to a total volume of 1,410m^3 in 2030[2].

The ICEDA facility to be commissioned by EDF in 2013 (Bugey site) will have a storage capacity of approximately 4,000 m^3. It will also be used to store LLW-LL and LILW-SL packages awaiting shipment for disposal.

In conclusion, regarding HLW and ILW-LL packages, storage facilities at waste-producing sites should be capable of meeting the currently anticipated storage capacity and duration requirements laid down in the Act of 28 June 2006, as of 2015 (provided the necessary extensions are built) and until the deep repository is commissioned (scheduled for 2025).

1 In the 2009 National Inventory, this waste is associated with the ILW-LL management solution.

2 Conditioned waste volume as at the end of 2030.

storage requirements on the future deep repository site and on waste-producing sites after 2025

An anticipated service life of approximately 100 years for storage facilities would be consistent with the service life of the repository.

2.1 Description of various requirements

Andra is exploring various possibilities for the integration of additional storage facilities within the future deep repository site.

For HLW and ILW-LL packages, such storage facilities will act as a buffer between transportation and disposal operations. In addition, the integration of storage facilities is in line with the principle of repository reversibility.

The storage facilities will help waste-producing facilities organise operating campaigns as and when decisions are taken to commission new reactor units, in line with the gradual repository management plan. For example, in the case of HLW produced by La Hague plants, periodic meetings could be held to decide on a possible extension of the storage phase so as to benefit from additional thermal decay (beyond the mandatory first 60 years of storage). In addition, these facilities will be used to manage waste packages to be retrieved from the repository, where applicable.

2.2 Specific characteristics of storage facilities within the repository site

In order to act as intermediate buffers, HLW and ILW-LL storage facilities will need to be multi-purpose facilities capable of accommodating the highly variable characteristics of the different types of waste packages (dimensional characteristics, etc.). The number of storage facilities to be built will depend on their degree of multi-purpose adaptability.

The implementation of reversibility would not impose the construction of surface storage facilities with a capacity equivalent to that of the repository, but the facilities would need to be of modular design. In this way, the facilities would not impose technical decision-making limits regarding gradual repository management and waste package retrieval, if necessary.

An anticipated service life of approximately 100 years for storage facilities would be consistent with the service life of the repository and with the period of time during which waste package retrieval must remain possible.

2.3 Delivery schedules

The schedule for the delivery of different waste package types to the repository site is currently being studied. It will depend on the construction schedule for the disposal cells and on the adaptability of the waste reception, inspection, storage and containerisation facilities. In the case of exothermic HLW packages, it will also depend on the required thermal decay time.

It will be possible to transfer non-exothermic HLW packages to the repository site immediately after commissioning. Assuming that disposal operations will be completed from 2025 to 2035, the HLW storage facilities will be able to accommodate CSD-V packages with a heat output ranging from 700 to 1,200 W as of 2035. This scenario would require the construction of on-site storage facilities with a storage capacity of approximately 3,000 m^3, allowing a minimum waiting time of approximately 15 years for CSD-V packages.

This scenario would have two advantages: it would avoid a temporary shutdown of the HLW storage facilities (for at least 15 years), and avoid the need for new storage facility extensions for CSD-V packages at the La Hague site beyond 2035.

appendix 5 French radioactive waste sea-dumping campaigns

1 introduction

Radioactive waste sea-dumping campaigns were conducted by eight European countries for three decades starting in the late 1940s. These campaigns were initiated in shallow territorial waters and were subsequently performed in deep waters off the continental slope. They were discontinued in 1982 after the signature of an international agreement known as the London Convention.

There is a total of 33 geographic sites located in the Atlantic Ocean and adjacent seas (English Channel, North Sea, Irish Sea, Baltic Sea), of which 17 were exclusively used by the United Kingdom. Germany, Italy and Sweden have occasionally dumped small quantities of radioactive waste. Belgium, Switzerland and the Netherlands also participated in dumping campaigns in shallow waters (6, 3 and 4 sites respectively).

France conducted two dumping campaigns in the Atlantic Ocean, in 1967 and 1969, at two separate sites at depths of over 4,000 metres. In addition, three sites in the Pacific Ocean were used until 1997 for radioactive waste generated by nuclear testing. No French campaigns were conducted in the English Channel (England and Belgium conducted campaigns in the Casquets trench off Cherbourg, despite its international waters status).

2 historical and institutional context

In the early 1950s, dumping radioactive waste at sea was considered as a disposal solution. At the time, the scientific community considered this solution as the most appropriate for significant dilution and isolation times, particularly for tritiated waste. In this context, tritium became the main contributor of the activity dumped near and off the coasts of Europe for over 30 years.

Until the mid 1960s, each country freely organised its dumping campaigns according to its own rules. Subsequently, these campaigns became the subject of detailed scientific and technical studies coordinated by the Nuclear Energy Agency (NEA), an OECD agency responsible for issuing relevant recommendations to Member States.

In 1967, the OECD began to coordinate the collection of waste by European states applying for membership with a view to ensuring the technical optimisation of dumping operations. It was within this framework supervised by the NEA that France participated in the 1967 and 1969 low- and intermediate-level waste dumping campaigns.

France no longer participated in subsequent campaigns, which were organised at a single site recommended by the OECD, different from the sites previously used during French participation. This site is a rectangular area measuring approximately 4,000 km^2, located 1,000 km off the French coast, where 123,000 waste packages were dumped over a period of 12 years.

3 statement of radioactive waste dumping campaigns in the North Atlantic

Beginning on a very small scale in 1948, the quantity of activity dumped gradually increased to reach a maximum of 5 to 7 petabecquerels (1 PBq = 10^{15} Bq) per year in the early 1980s, shortly before the European moratorium on low-level radioactive waste disposal at sea (adopted in 1983).

Between the Irish Sea and the Azores, a total of 150,000 tonnes of low and intermediate-level waste has been dumped by 8 countries, for the most part at approximately 15 deep-water sites. The total activity dumped from 1948 and 1982 amounts to approximately 42 PBq, of which nearly one-third corresponds to tritium activity. Of this total, French waste amounts to:

- less than 1% in terms of activity (0.35 PBq out of 42 PBq dumped),
- slightly less than 10% in terms of mass (14,200 tonnes out of 150,000 tonnes dumped).

The two French radioactive waste dumping campaigns were conducted at two different locations:

- in 1967, off the coast of Galicia (latitude 42° 50' N, longitude 14° 30' W, i.e. 370 km off the coast of Spain), at a depth between 4,590 and 5,310 metres,
- in 1969, off the coast of Ireland and Brittany, beyond the continental slope (latitude 49° 05' N, longitude 17° 05' W, i.e. 926 km off the coast of Brittany), in the "Porcupine", at a depth between 4,000 and 4,600 metres.

These two dumping campaigns amounted to a total of 46,396 low-level waste drums and containers, mainly containing liquid effluent settling sludge from Marcoule facilities, conditioned in metallic drums with or without bitumen cementation and in cemented containers:

- in 1967, 30,700 metallic containers (total alpha emitter activity: 0.0059 PBq, total beta-gamma emitter activity: 0.2126 PBq) and 896 cemented containers (total alpha emitter activity: 0.040 TBq, total beta-gamma emitter activity: 0.00037 PBq);
- in 1969, 14,800 cemented containers (total alpha emitter activity: 0.0025 PBq, total beta-gamma emitter activity: 0.1319 PBq).

statement of French radioactive waste dumping campaigns in the Pacific

4

From 1966 to 1996, France conducted 164 nuclear tests and 15 safety trials in the Pacific Ocean. The experiments were conducted in Mururoa and Fangataufa, 2 atolls of the Tuamotu-Gambier archipelago, 1,200 km from Tahiti. Located more or less at the half-way point, the Hao atoll was used as an advanced base for test preparation, follow-up and logistics.

Radioactive waste was generated at the three sites during the operation of nuclear test monitoring facilities and during their dismantling (after the last underground nuclear test in 1996). In addition, atoll and lagoon cleanup operations after the atmospheric nuclear tests of 1966 to 1974 also generated radioactive waste.

In 2005, detailed technical data on the history of French nuclear experiments in the Pacific was made available on the website of the French Ministry of Defence, including information on the treatment of the radioactive waste produced (buried in shafts or dumped at deep-water sites outside the lagoons).

Mururoa atoll

The first dumping operations were performed in 1967 north of Hao, at a depth of 2,500 metres. The last were performed in 1982 off the coast of Mururoa, at a depth of 3,000 metres. In all, 3,200 tonnes of essentially metallic waste were dumped at 3 sites a few thousand nautical miles from Mururoa (2 sites) and Hao (1 site). No dumping took place around Fangataufa.

The waste buried in shafts in Mururoa consists of 11,600 residue drums or bundles and approximately 7,700 m^3 of aggregates and scrap metal, with an alpha activity of 23 TBq and a beta-gamma activity of 0.7 TBq.

This radioactive waste came from:

- residues from decontamination facilities (Hao or Mururoa facilities ensuring decontamination of post-borehole drilling equipment after underground nuclear testing);
- residues from treatment of samples for post-test radiochemical analysis;
- essentially metallic components from dismantling operations.

Waste drums were used whenever possible, depending on the specific activity of the waste to be dumped. Bulky components were hoisted by helicopter to one of the dumping zones (e.g. metal tower components used for atmospheric nuclear testing) or dumped directly from a barge (Vautour aircraft, reactors, atmospheric sampling equipment). Residues were mostly conditioned in metallic drums filled with concrete.

This waste mostly contained short-lived, beta-gamma emitter radionuclides with a half-life of less than 10 years (^{140}Ba, ^{141}Ce, ^{144}Ce, ^{60}Co) and others with a half-life close to 30 years (^{137}Cs, ^{90}Sr).
Between 1981 and 1997 (date of completion of radiological cleanup of facilities), dumping operations were abandoned, with waste disposal performed in two deep shafts in Mururoa (one of which had been previously used) and in a number of unsealed shaft heads used during testing.
In addition, approximately 5,000 tonnes of uncontaminated scrap metal were dumped off the coast of Hao after July 2000.

The following table provides a summary of radioactive waste disposal in the Pacific:

Hao site	Mururoa sites
Location French Polynesia, Tuamotu archipelago (1,100 km southwest of Tahiti, 500 km northwest of Mururoa). "Hôtel" site: 7.4 km north of the atoll, measuring approximately 1 km² at a depth of 2,500 metres.	**Location** French Polynesia, Tuamotu-Gambier archipelago (1,200 km southeast of Tahiti). Site 1 ("Novembre" site): approximately 6 km north of the atoll, measuring 20 km² at a depth between 2,000 and 3,200 metres. Site 2 ("Oscar" site): approximately 8 km northwest of the access passage to the lagoon, measuring 60 km² at a depth between 2,000 and 3,200 metres.
Brief description From 1967 to 1975, waste partly resulting from the treatment of samples collected from atmospheric test clouds. 19 waste dumping campaigns including: 5 Vautour aircraft, ATAR reactors, Matra rockets used for aerosol sampling and batches of miscellaneous metallic components.	**Brief description** "Novembre" site: from 1972 to 1975, unconditioned metallic waste dumped during 5 operations via heavy helicopter (tower components used for atmospheric nuclear testing, large debris from 5 safety trials conducted at the time). "Oscar" site: from 1974 to 1982, concrete waste containers and bulk waste dumped during 14 operations by boat (waste resulting from cleanup operations in the northern part of the atoll, basaltic rock samples from post-test boreholes).
Waste disposal 310 tonnes in concrete drums. 222 tonnes of bulk waste. Total alpha activity of 0.03 GBq and total beta-gamma activity of 15 GBq (approximately 1/3 due to fission products from contaminated atmospheric sampling equipment [Matra rockets, aircraft]).	**Waste disposal** "Novembre" site: 76 tonnes of bulk metallic waste with a total alpha activity of 7 GBq and a total beta-gamma activity of 1 GBq. "Oscar" site: 1,280 tonnes in concrete containers and 1,300 tonnes of bulk waste (cleaned-up heavy metals) with a total alpha activity of 60 GBq and a total beta-gamma activity of 6 GBq.

location of radioactive waste sea-dumping sites

5

5.1 Location of Atlantic sites

In June 1984, a French programme to study the environment of the OECD/NEA site was conducted in collaboration with the IFREMER Institute and CEA using an unmanned submersible equipped for a photographic survey (EPI-CEA campaign). Over a linear distance of 61 km (1 photo every 5 seconds at 3 or 4 metres from the bottom), 6 containers were detected, including 1 concrete package. This shows the significant geographic dispersal of the waste packages dumped at this site (total of 123 000). The containers detected appeared to be intact. Two containers dumped in 1979 were successfully identified. The geographic distribution on the ocean floor is very heterogeneous considering the very large area of the site.

Based on the results of scientific programmes directly or indirectly concerning the surveillance of old dumping sites, it appears that the radioactivity observed in the waste dumping zone is indistinguishable from or even lower than the fluctuations of the natural radioactivity on the ocean floor. The OSPAR Commission (composed of scientists from the 15 countries most concerned by radioactive waste dumping) considers that emissions in the immersion zone *"pose only a negligible radiological risk to human health, even though it is difficult to draw definitive conclusions on the environmental impact."*

Radioactive waste dumping in the 1960s

5.2 Location of Pacific sites

As part of the continuous radiological monitoring of French Polynesia (excluding Mururoa and Fangataufa), the French Institute for Radiological Protection and Nuclear Safety (IRSN) actively contributes to assessing the radiological consequences of atmospheric and underground nuclear testing. Terrestrial, lagoon and marine samples from a vast region encompassing the 4 archipelagos of French Polynesia (Marquises, Tuamotu-Gambier, Société, Australes) are collected and analysed for this purpose.

The Ministry of Defence is responsible for the radiological monitoring of the Mururoa and Fangataufa sites. Monitoring is performed by the Nuclear Test Facility Monitoring Department (DSCEN) of the French Armament Procurement Agency (DGA), with the support of the French Atomic Energy Commission (CEA). External exposure and atmospheric aerosol levels are measured monthly at Mururoa, and physical and biological environmental sampling campaigns are conducted in the atolls on an annual basis. These radiological monitoring activities cover the terrestrial, lagoon and marine environments of the atolls within the 22 km territorial water boundary. In Mururoa and Fangataufa, marine samples are collected every 4 years (water, plankton, deep-sea pelagic fish). Ocean water is sampled at 6 different depths: near the surface and at 200, 400, 600, 800 and 1000 metres.

The radionuclides measured in 2006 between Mururoa and Fangataufa are present in very low concentrations, for the most part below or near the detection limit of radioactivity measurement devices. This is the case of ^{137}Cs, ^{90}Sr, ^{239}Pu and ^{240}Pu. The results of these monitoring activities for the year 2006 are available on the Ministry of Defence website.

The radionuclides measured in 2006 between Mururoa and Fangataufa are present in very low concentrations, for the most part below or near the detection limit of radioactivity measurement devices.

Further information:

IAEA 1991: "Inventory of radioactive material entering the marine environment as a result of radioactive waste disposal at sea" (TECDOC 588).

IAEA 1999: "Inventory of radioactive waste disposals at sea" (TECDOC 1105).

Ministry of Defence: "La dimension radiologique des essais nucléaires français en Polynésie; à l'épreuve des faits", November 2006, 477 pages.

appendix 6

Glossary

Terms	Definitions
Actinide	Natural or artificial radioelement with an atomic number between 89 (actinium) and 103 (lawrencium). For certain authors, the actinide series begins with element 90 (thorium). This series corresponds to the filling of electron shell 5f.
Activity	Number of nuclear isomeric decays or transitions produced per unit time in a radioactive substance. The unit of activity is the becquerel.
Back end of fuel cycle	Nuclear fuel cycle operations after use in the reactor, from spent fuel processing to radioactive waste disposal.
Basic nuclear installation (INB)	In France, a nuclear facility subject to specific regulations on account of its type and characteristics or the quantities or activity levels of all the radioactive substances it contains.
Becquerel (Bq)	International measurement unit for activity. It corresponds to the activity of a quantity of radioactive nuclides for which the average number of nuclear isomeric decays or transitions per second is equal to 1 (1 Bq = $1 s^{-1}$). This unit replaces the curie (1 Ci = 3.7 10^{10}Bq). Multiples are typically used: megabecquerel (MBq, one million becquerels), gigabecquerel (GBq, one billion), terabecquerel (TBq, one thousand billion), petabecquerel (PBq, one million billion) or exabecquerel (EBq, one billion billion).
Bituminised sludge	Sludge resulting from coprecipitation operations in liquid radioactive effluent treatment plants and conditioned in bitumen.
Burnup rate	Total energy released per unit mass of a nuclear fuel. Commonly expressed as megawatt-days per tonne.
Chemical toxin	Chemical substance or element liable to have harmful effects on human health in case of ingestion and/or inhalation. The health impact of a chemical toxin is quantified based on its reference toxicity value, a generic parameter comprising the various toxicity values used to establish a relationship between a dose and an effect (case of a toxin with threshold effect), or between a dose and a probability of effect (case of a toxin without threshold effect, often carcinogenic). Various elements or substances used in the nuclear field or present in fission products exhibit radioactive toxicity. The following in particular are taken into consideration in studies for deep radioactive waste disposal: arsenic, cadmium, cyanide, chromium, mercury, nickel, lead, antimony, selenium, boron, uranium, beryllium and asbestos.
Cladding waste	Radioactive waste composed of metallic structures of spent fuel assemblies from water-cooled reactors. This term is also used to refer to spent fuel assemblies from sodium-cooled fast neutron reactors.
Conditioned equivalent volume	Volume of a waste package after it has undergone all the treatment and conditioning operations currently considered by the waste producer.

Conditioning matrix	Solid material used to immobilise or confine radioactive waste, or simply to improve the crushing resistance of waste packages.
Confinement (of radioactive materials)	Implementation of a set of measures to prevent the dispersal of unacceptable quantities of radioactive materials outside a predetermined area.
Container	In the nuclear industry, a term referring to a movable sealed vessel used for transport, interim storage or disposal operations.
Dismantling	1 - Technical operations performed to dismantle and possibly scrap nuclear equipment or part of a nuclear facility. 2 - In French regulations, term referring to the demolition phase of a nuclear facility, comprising all operations after the decommissioning decree.
Enriched recycled uranium	Enriched uranium obtained through enrichment during spent fuel processing. The term enriched reprocessed uranium is also used.
Fast neutron reactor	Nuclear reactor in which the presence of materials potentially causing neutron slowdown is limited, thereby allowing fission reactions to be mainly produced by fast neutrons
Final radioactive waste	Radioactive waste that can no longer be processed under current technical and economic conditions (e.g. extraction of recoverable materials, reduction of pollution or hazard potential).
Fissile	1 - Term used to describe a nucleus that is capable of undergoing fission through interaction with neutrons in all energy ranges, particularly thermal neutrons. Actinide nuclei with odd neutron numbers are either fissile (^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu, etc.) or short-lived ß- emitters (^{237}U, ^{243}Pu, ^{244}Am, etc.). In the case of the latter, the probability of neutron-induced fission is negligible, even at high flux. 2 - Term used to describe a substance containing one or more fissile nuclides. In such cases, the term fissile material is used.
Fission product	Nuclide resulting from a nuclear fission reaction after prompt de-excitation of fission fragments. When they exit the nuclear reactor, most fission products (approximately 95% in mass) are stable (approximately 85%) or short-lived (approximately 10%). A few (approximately 5%), are long-lived (e.g. ^{99}Tc, ^{129}I).
Front end of fuel cycle	Nuclear fuel cycle operations from mining to fuel fabrication.
Fuel assembly	Group of fuel elements that remain attached to each other, particularly during reactor core refuelling operations.
Gas-cooled graphite-moderated reactor	Generation 1 nuclear fission reactor using graphite as moderator and carbon dioxide gas as coolant.
Graphite waste	Term used in France for a radioactive waste category comprising graphite from old gas-cooled graphite-moderated reactor cores. This graphite contains tritium and long-lived elements (carbon-14, chlorine-36).
Heavy metal	In the nuclear fuel field, term generally referring to all actinides. In practice, it is mainly used for uranium and plutonium. For example, when calculating the burnup per tonne of initial heavy metal, the latter quantity corresponds to the tonne of uranium or plutonium contained in the fuel prior to irradiation.
Hulls and end caps	Radioactive waste composed of LWR fuel assembly hulls and upper and lower end caps.
Isotope	1 - Any nuclide of a given element. 2 - All the nuclides of a single element.
Long-lived (LL)	See long-lived waste

Long-lived waste	Radioactive waste in which the main radioactive components are radionuclides with a radioactive half-life greater than 31 years.
"Marked" site	Site exhibiting traces of natural or artificial radionuclides that can be detected without necessarily requiring any specific action.
Minor actinide	Common term referring to neptunium, americium or curium formed during nuclear combustion.
MOX fuel	Abbreviation for mixed-oxide fuel.
Nuclear fission	Disintegration of a heavy nucleus, generally by splitting into two nuclei with atomic masses ranging from 70 to 170.
Nuclear fuel	Substance containing **nuclides** that are consumed by **fission** in a nuclear reactor to sustain a nuclear chain reaction.
Nuclide	Nuclear species characterised by its atomic number Z and its mass number A (i.e. number of nucleons in its nucleus). Each chemical element generally possesses several isotopic nuclides. A nuclide is designated by its chemical symbol, preceded by its mass number A as a superscript and its atomic number Z as a subscript, e.g. $^{238}_{92}U$.
Plutonium	Element with atomic number Z = 94. It was initially produced for military applications. Generated by uranium-238 irradiation, it is currently used as a MOX fuel component in certain light-water reactors. It is also the fuel used in most fast neutron reactor studies.
Polluted site	In a radioactive contamination context, term used to describe an area or site significantly contaminated by natural or artificial radioactive substances.
Pressurised water reactor (PWR)	Thermal neutron reactor using light water as moderator and coolant. This water is maintained in the liquid state inside the reactor core through pressure high enough to prevent bulk boiling at the operating temperature.
Radioactive cleanup	Operations performed in a nuclear facility or site, aiming to eliminate or reduce radioactivity (particularly through decontamination or removal of radioactive materials) so as to recover radioactive substances in a controlled manner.
Radioactive contamination	Unwanted presence of significant quantities of radioactive substances on the surface or within any environment.
Radioactive half-life	Interval of time required for one-half of the atomic nuclei of a radionuclide to decay. This value is an essential characteristic of each radionuclide.
Radioactive material	Radioactive substance for which subsequent use is planned or intented (after processing, if necessary).
Radioactive substance	Substance containing natural or artificial radionuclides where the activity or concentration justifies radiological protection monitoring.
Radioactive waste	Radioactive substances for which no subsequent use is planned or intended.
Radioactive waste conditioning	Operations intended to prepare **radioactive waste** for subsequent **transport**, **storage** or **disposal**. Note: These operations may include compaction, ***embedding***, ***vitrification***, cementation, bituminisation and containerisation.

Radioactive waste disposal	Operation consisting in placing radioactive waste at a facility specially desinged for the potentially definitive disposal of the substances concerned and in compliance with human health, safety and environmental protection requirements.
Radioactive waste disposal facility	Facility intended for long-term disposal of radioactive waste. Disposal at surface facilities, near-surface facilities or facilities approximately 500 m below the surface may be considered, depending on the radiological risks associated with the waste. The term reversible disposal is used when the waste can be removed during a predefined period, at the cost of some - possibly extensive - work.
Radioactive waste package	Conditioned and packaged **radioactive waste.**
Radioactivity	Property of a nuclide that allows it to undergo spontaneous transformation (into another nuclide) with emission of radiation (particles, X-rays, gamma rays, etc.), or spontaneous fission with emission of particles and gamma rays. In addition to spontaneous fission, the main forms of radioactivity are beta radioactivity (β^+, β^-, internal conversion), gamma radioactivity and electron-capture radioactivity. Gamma radioactivity often accompanies the other forms.
Radioelement	1 - Chemical element in which all the isotopes are radioactive. 2 - Term sometimes used for a radioisotope or radionuclide (not recommended).
Radiological protection	Set of measures intended to protect the health of populations and workers against the effects of ionising radiation and to ensure compliance with basic standards. It also includes implementing the necessary means to achieve these objectives.
Radionuclide	Radioactive nuclide.
Rare earth	Element from the group comprising the lanthanides and two chemically similar elements (yttrium and scandium).
Recycled uranium	Term referring to uranium resulting from spent fuel processing. The terms reprocessed or processed uranium are also used.
Rod	A slender tube sealed at both ends, used as a component of a nuclear reactor core when it contains fissile, fertile or absorber material.
Scenario	Set of hypotheses regarding events or types of behaviour, used to describe the possible evolutions of a system in time and space.
Short-lived (SL)	See short-lived waste.
Short-lived waste	Radioactive waste containing significant quantities of radionuclides with a radioactive half-life less than or equal to 31 years.
Spent fuel	**Nuclear fuel** discharged from a reactor after irradiation and sent to a storage, disposal or processing facility.
Spent fuel processing	Also known as spent fuel reprocessing. Operations performed on spent fuel from nuclear reactors in order to extract recoverable materials (e.g. uranium, plutonium) and condition the remaining waste.
Storage (of radioactive material or waste)	Operation consisting in temporarily storing radioactive substances at a specially designed surface or near-surface facility until they can be recovered.
Tritiated waste	Radioactive waste containing tritium, possibly requiring specific management due to the high mobility of this element.

Tritium	Hydrogen isotope with a mass number of 3. Tritium is a low beta energy emitter (average of 13 KeV) with a half-life of 12.3 years. It is used in a large number of marked molecules. Current nuclear fusion projects are all based on the deuterium-tritium reaction. In civil industrial applications, tritium is first and foremost a radioactive waste product requiring specific management due to its high mobility.
UOX fuel	**Nuclear fuel** made from uranium oxide. There are different types of UOX fuel: - UOX1: Fuel produced from natural uranium enriched to 3.25% U235, with an average **burnup rate** of 33 GWd/t - UOX2: Fuel produced from natural uranium enriched to 3.7 % U235, with an average **burnup rate** of 45 GWd/t - UOX3: Fuel produced from natural uranium enriched to 4.5% U235, with an average **burnup rate** of 55 GWd/t
Vitrified waste	In the nuclear field, term referring to radioactive waste conditioned in a glass matrix. Fission product solutions were the first waste to be vitrified. There are plans for other less radioactive waste to be vitrified in the future.
Waste producer (or generator)	Organisation producing radioactive waste and possibly performing primary conditioning operations.
Waste treatment	Mechanical, physical or chemical operations intended to modify the characteristics of waste materials. The objective is to make the waste suitable for conditioning.

2009 EDITION
OF THE NATIONAL INVENTORY OF RADIOACTIVE MATERIALS AND WASTE

- Synthesis Report
- Geographical Inventory
- Catalogue describing the families
- Summary Report

All of these documents are available on CD-Rom and on the Andra internet website **www.andra.fr** where you can also make your suggestions

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