2012

Synthesis report

NATIONAL INVENTORY of Radioactive Materials and Waste

ANDRA
Mastering radioactive waste

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

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

« Over the last few decades, France has implemented a responsible policy for management of the waste generated by the activities that use radioactivity. Thus in the early 1990s, the French Parliament passed an act setting up the National radioactive waste management agency (Andra), a public establishment that is independent of the producers of radioactive waste, and entrusted it with the task of finding and designing safe solutions for managing all French radioactive waste.

As part of its mission of general interest, Andra is also tasked with periodically listing all the radioactive materials and waste in France and drawing up forecasts of their future production. It makes every effort to provide as complete and exhaustive a picture as possible as to their nature, quantity and locations. Under the French Act of 28 June 2006, Andra is required to update and publish this information every three years, in the form of the present *National Inventory*.

To ensure transparency, Andra has set up a steering committee with a broad membership to monitor preparation of the *National Inventory*. Chaired by Andra Chief Executive Officer, the steering committee includes representatives of the institutions involved (ministries, Nuclear safety authority, National committee for transparency and information on nuclear safety, etc.), waste producers and environmental protection associations. It thus constitutes a platform for expressing the multiple standpoints concerning the issues involved in management of radioactive waste, to ensure that the *National Inventory* meets the expectations of the majority of people.

A vector of information and transparency on a subject that is of interest to many of our fellow citizens, the *National Inventory* also constitutes a valuable tool for guiding the French policy on management of radioactive materials and waste, formalised in the National plan for management of radioactive materials and waste (PNGMDR). The *National Inventory* provides a way of ensuring controlled management of the French waste generated to date and in the future. It thus meets the objective set for the Member States by the European directive on radioactive waste adopted on 19 July 2011. The directive recommends that each Member State should implement a national programme for management of fuel and waste, based on drawing up inventories.

On the basis of the declarations by each holder of waste, the 2012 edition of the *National Inventory* lists the waste generated as at 31 December 2010, together with forecasts of the quantities of waste expected by 2020 and 2030. A forward-looking analysis is also performed, covering the longer term, based on two contrasting scenarios covering the future of nuclear facilities and France's long-term energy policy. The *National Inventory* also lists the radioactive materials stored with a view to their recycling.

At the time of publication of this edition, the Cigéo project for a deep geological repository for radioactive waste is entering a crucial phase; the 2006 act stipulates that Andra is to submit a construction licence application for this facility in 2015 after public consultation and discussion, scheduled for 2013. Thus the 2012 edition of the *National Inventory* provides updated data on the waste that is to be disposed of in Cigéo.

Like the previous one, the 2012 edition of the *National Inventory* takes the form of four volumes: Synthesis Report, Summary, Catalogue of families, and Geographical Inventory. Both the synthesis report and summary versions are available in multimedia format on a USB key. An electronic version is also available on the Internet, with interactive links developed since the previous edition. The Synthesis Report has been enriched with special reports to provide a wider view of certain fields linked to radioactive waste, including waste with technically-enhanced radioactivity, management of spent sealed sources, and sea-dumping of waste, which has been carried out in the past.

Andra attaches great importance to improving the presentation of the Inventory in its successive editions, concerning its form and its content alike. The comments of our readers help us to enrich the *National Inventory* and make it useful for as many people as possible; they are of course always welcome.

We trust this fourth edition will provide you with some interesting reading.

Marie-Claude Dupuis
Chief Executive Officer of Andra

François-Michel Gonnot
Chairman of the Board of Andra

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Radioactive waste and its management

1.1 Sources of radioactive waste

Since the beginning of the twentieth century, many uses of the properties of radioactivity have generated radioactive waste.

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 centres also contribute, to a lesser extent, to production of radioactive waste, as do certain industries that use radioactive substances.

The *National Inventory* sets out the sources of radioactive waste on the basis of **five economic sectors** that lead to production, holding or management of radioactive waste *(see box on page 10)*.

Nuclear power sector

This includes mainly the nuclear power plants, together with the nuclear fuel production and processing plants (extraction and processing of uranium ore, chemical conversion of uranium concentrates, fuel enrichment and manufacturing, spent fuel processing and recycling).

1.

Defence sector

This covers mainly activities linked to nuclear deterrents, including the nuclear propulsion systems of certain ships and submarines, together with the corresponding research activities.

Research sector

This includes research in the civil nuclear field, medical research laboratories, particle physics, agronomics, chemistry, etc.

Industry sector (other than nuclear power plants)

This covers mainly extraction of rare earth elements and production of sealed sources, together with various applications such as welding inspections, sterilisation of medical equipment, sterilisation and preservation of foodstuffs, etc.

Medical sector

This includes therapeutic, diagnosis and research activities.

In the past, the sectors that have made the largest contributions to production of radioactive waste in France are the nuclear power, research and defence sectors.

In conformity with Book V, Title IV, chapter II, article L. 542-1 of the Environment Code as amended by the French Act of 28 June 2006, **the producers of radioactive waste are responsible for proper management of their waste until it is taken to a final disposal site.**

Book V, Title IV, chapter II, article L. 542-1-1 of the Environment Code stipulated by the French Act of 28 June 2006 [I]*, defines a certain number of concepts that it is useful to remember when consulting the National Inventory of radioactive materials and waste.*

“A radioactive substance is a substance that contains natural or artificial radionuclides whose activity or concentration justifies radiological protection monitoring.”

“A radioactive material is a radioactive substance for which a subsequent use is planned or intended, after processing if necessary.”

In some cases, processing of materials with a view to their recycling can create waste.

“Radioactive waste consists of radioactive substances for which no subsequent use is planned or intended.

Ultimate radioactive waste is radioactive waste that can no longer be processed under current technical and economic conditions, and in particular through extraction of its recyclable materials or by reduction of its polluting or hazardous nature.”

“A nuclear fuel is considered as spent fuel when, after having been irradiated in the core of a reactor, it is definitively withdrawn from the reactor.”

As France has opted for processing spent fuel to recover the materials it contains whenever possible, such fuel is not considered as radioactive waste.

These concepts are to be supplemented by that of waste with technically-enhanced naturally occuring radioactive waste (TENORM). TENORM waste is waste generated by transformation of raw materials that contain naturally-occurring radionuclides but are not used for their radioactive properties.

In fact, all substances, and especially minerals, contain naturally-occurring radionuclides at trace levels, including uranium, thorium or potassium.

Some non-nuclear industries linked to chemistry, production of metals or energy can be a source of TENORM waste, due to production or extraction processes that lead to concentration of natural radionuclides.

Activities using radioactive substances can lead to controlled discharges into the environment, in gaseous or liquid form. Such discharges lie outside the scope of the *National Inventory of radioactive materials and waste*.

Discharges from basic nuclear installations (INBs) are described and quantified in the public reports that their operators are required to issue each year under the French Act of 13 June 2006 on transparency and safety in the nuclear field. The data concerning discharges from classified facilities for the protection of the environment (ICPEs) are gathered each year by the French ministry for ecology and made available to the general public on the Internet.

[I] *Planning Act 2006-739 of 28 June 2006 on long-term management of radioactive materials and waste.*

Radioactive waste consists of radioactive substances for which no subsequent use is planned or intended **(Article L. 542-1-1 of the Environment Code).**

Producer of radioactive waste

Any person whose activities generate radioactive waste (initial producer of waste) or any person carrying out waste processing operations that lead to a change in the nature or composition of such waste (subsequent producer of waste) (L. 541-1-1).

Holder of radioactive waste

Producer of radioactive waste or any other persons in possession of radioactive waste (L. 541-1-1).

An item of radioactive waste can have several holders between the time of its production and the time of its elimination (successively the holder-producer, then the transport entity, the operator of the storage site, and the operator of the disposal site).

Management of radioactive waste

Collection, transport, recycling and elimination of radioactive waste, and more generally all activities playing a part in organisation of radioactive waste management, from its production to its final treatment, including the trade or brokering activities and supervision of all these operations (L. 541-1-1).

Responsibilities

Any producer or holder of radioactive waste:

- is required to manage it, or have it managed, in compliance with the provisions set out in this chapter;
- is responsible for management of such waste until it is finally disposed of or recycled, even if the waste is transferred to a third party for treatment;
- must make sure that the person to which it entrusts the radioactive waste is licensed to deal with it (L. 541-2).

The producers of spent fuel and radioactive waste are responsible for these substances, without prejudice to the responsibilities of their holders in their capacity as persons responsible for nuclear activities (L. 542-1).

These provisions mean that the producer is responsible for its radioactive waste and the obligations placed on it until its final elimination in application of article L. 541-2 (ensuring its management, treating the waste or arranging for its treatment, guaranteeing the quality and properties of the waste, and bearing the costs and responsibility for such damage as may be caused by the waste).

The holders which are not producers are responsible for their nuclear activities (security and safety of the facilities, activities and the radioactive waste transported, stored, or disposed of).

1.1

Obligations concerning declarations to the *National Inventory*

These obligations are defined in the decree of 29 August 2008 [II]:

"**Art. R. 542-67.** For the purpose of drawing up the *National Inventory* provided for under section 1 of article L. 542-12, any operator of a site accommodating one or more basic nuclear installations, or one or more defence-related nuclear facilities, defined in article R. 1,333-37 of the French Defence Code, or one or more facilities classified for the protection of the environment as set out in sections 1,715 or 1,735 of the nomenclature, or several of these categories of facilities, is required to forward to the National agency for radioactive waste management each year an inventory of the radioactive materials and waste on that site, as at 31 December of the year concerned."

"The Inventory, accompanied by a brief presentation of the site and information concerning the administrative body under whose responsibility it is placed, includes a description of the radioactive materials and waste, giving their physical characteristics and the quantities involved. The radioactive waste is grouped by family."

"If the site has a basic nuclear installation showing the characteristics of a nuclear reactor, a plant for processing of spent nuclear fuel, or a storage or disposal facility for radioactive substances, the operator supplements the annual inventory with an appendix showing the breakdown by producer and by family of radioactive waste on the site."

"For a defence-related nuclear facility, the inventory only contains a description of the radioactive waste concerning that facility."

"**Art. R. 542-68.** Any person responsible for nuclear activities and any head of an enterprise mentioned in article L. 1,333-10 of the Public Health Code" – i.e. using materials containing natural radionuclides that are not used for their radioactive, fissile or fertile properties – "that is not within the scope of the provisions set out in article R. 542-67 of this Code, is required to communicate to the National agency for radioactive waste management each year an inventory of the radioactive waste stored, as at 31 December of the previous year, and showing the management system used."

"**Art. R. 542-69.** Any operator of a site mentioned in article R. 542-67 is required to communicate to the National agency for radioactive waste management, every three years, a report providing information for that site concerning the forecast quantities of radioactive materials by family. If no definitive management solution suitable for such waste has been adopted, the report gives details of the types of storage facilities envisaged, their available capacities and their planned operating duration.

For a defence-related nuclear facility, the three-yearly report only includes a description of the radioactive waste concerning that facility."

[II] *Decree No. 2008-875 of 29 August 2008 on application of article 22 of Planning Act No. 2006-739 of 28 June 2006 on long-term management of radioactive materials and waste.*

1.2
Classification of radioactive waste and management solutions

The physical and chemical nature, and the level and type of radioactivity, are characteristics that differ from one type of waste to another. Radioactive waste usually contains a mixture of radionuclides: uranium, caesium, iodine, cobalt, radium, tritium, etc. Its levels and periods of radioactivity vary depending on its composition.

In France, classification of radioactive waste is based mainly on two parameters [III]: the level of radioactivity and the radioactive half-life [1] of the radionuclides present the waste.

The following waste radioactivity levels are distinguished:

- very-low-level;
- low-level;
- intermediate-level;
- high-level.

Waste is classified according to radioactive half-life as follows:

- very short-lived waste, whose radioactivity is halved after 100 days or less;
- short-lived waste, whose radioactivity comes mainly from radionuclides that have half-lives shorter than or equal to 31 years;
- long-lived waste, which contains a large quantity of radionuclides with half-lives longer than 31 years.

To manage each type of waste, it is necessary to implement or develop specific means that are suitable for the hazard levels involved and to their changes over time.

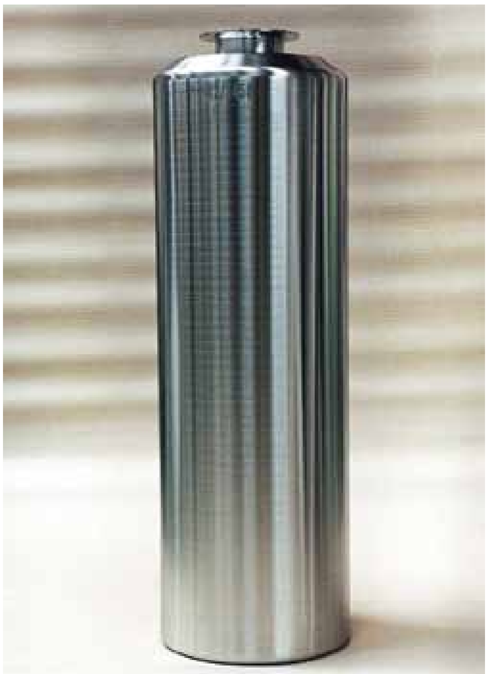
There are thus five categories of waste.

Waste has various levels of radioactivity over various lengths of time, depending on its composition.

1.2

1 *The radioactive half-life quantifies the time after which the initial activity of a given quantity of a radionuclide is divided by two.*

[III] *Decree No. 2012-542 of 23 April 2012 on application of article L. 542-1-2 of the Environment Code and setting out the provisions concerning the National plan for management of radioactive materials and waste (PNGMDR in French).*



Package of vitrified waste (HLW)

High-level waste (HLW)

This type of waste brings together most of the waste radioactivity in a relatively small volume, and it comes mainly from the nuclear power industry. It corresponds to the non-recyclable residues left after processing spent fuel. This waste is vitrified in stainless steel containers.

Because of its high levels of radioactivity, this type of waste generates heat. The level of radioactivity of HLW waste is several tens of billions of becquerels (Bq) per gram.

It contains short-lived fission products such as caesium-134 and caesium-137, or long-lived fission products such as technetium-99, activation products and minor actinides, some of which have half-lives of several thousand years, such as neptunium-237.

Long-lived intermediate-level waste (ILW-LL)

This waste comes mainly from the structures that contain spent fuel (cladding hulls and end caps) or from residues linked to operation of nuclear facilities (waste stemming from treatment of effluents, equipment, etc.). It is characterised by the presence of significant amounts of long-lived radionuclides such as nickel-63.

The level of radioactivity of this waste is usually between a million and a billion becquerels per gram, i.e. lower than that of HLW waste by a factor of 10 to 100.

Spent fuel structure waste before conditioning (ILW-LL)

HLW and ILW-LL, usually conditioned in packages, is currently stored until such time as a definitive disposal site is made available. Under the Planning Act No. 2006-739 of 28 June 2006, Andra is entrusted with the task of **carrying out studies and research to select a site and design a deep reversible disposal facility** (at a depth of 500 metres) **to accommodate this waste, Cigéo** (the deep geological repository) which is scheduled to be commissioned in 2025, subject to licensing *(see special report 4)*.

1.2

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

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

- **radium-bearing waste** contains naturally-occurring radionuclides, including a significant quantity of radium and/or thorium. It comes mainly from research activities and chemical processing of ores. Other types of radium-bearing waste can also come from clean-ups of legacy sites polluted with radium, which Andra is making safe as part of its general interest mission. The level of radioactivity of this waste is usually between a few tens and a few thousand becquerels per gram.

The radionuclides that it contains are mainly long-lived alpha emitters such as radium, uranium or thorium.

Radium-bearing waste

- **graphite waste** comes from operation and dismantling of the first nuclear power plants (GCR reactors: gas-cooled graphite-moderated process) and certain experimental reactors that have been decommissioned. This type of waste shows levels of activity between ten thousand and several hundred thousand becquerels per gram. In the short term, the radioactivity of graphite waste is mainly due to nickel-63, tritium and cobalt-60.
Over the longer term, carbon-14 becomes the main contributor to the radioactivity.

This LLW-LL category also includes other types of waste such as **spent sealed sources,** certain **packages of legacy bitumen, etc.** Work is currently in progress within the framework of the PNGMDR [2] to determine the scope.

Disposal of this waste is being studied at present within the framework of planning act No. 2006-739 of 28 June 2006.
In 2008, Andra started looking for a suitable site for a near-surface disposal facility for LLW-LL. In 2009, the two municipalities selected by the French government, on the basis of an analysis report drawn up by Andra, decided to withdraw their applications under pressure from the opponents.
In June 2010, the French government set new guidelines for the project. In particular, it asked Andra to continue its studies concerning knowledge, treatment and conditioning of LLW-LL and re-open the management options for such waste. A report on the work will be submitted to the French government at the end of 2012. It will enable assessment of the opportuneness of setting up new management solutions, definition of a new schedule for the project, and proposal of changes to the site search procedure begun in 2008 *(see special report 4)*.

Graphite sleeve used in GCR reactors

2 *National plan for management of radioactive materials and waste.*

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

This is made up mainly of waste related to maintenance (clothing, tools, filters, etc.) and operation of nuclear facilities (liquid effluent treatment or gaseous effluent filtering).

It can also come from clean-up and dismantling operations on these facilities.

LILW-SL waste contains short-lived radionuclides, with radioactive half-lives of less than 31 years, such as cobalt-60 or caesium-137. It can also contain limited quantities of long-lived radionuclides.

The level of radioactivity of this waste is usually between a few hundred becquerels and a million becquerels per gram.

Some LILW-SL waste contains considerable quantities of tritium that require specific management (T-LILW-SL).

Low and intermediate level short-lived waste is disposed of in a surface facility and monitored during the time taken for its radioactivity to decay to levels with negligible impact.

On the Andra disposal sites, it is generally considered that this level is reached after 300 years.

These sites will therefore be monitored for at least 300 years. There are two sites of this type in France: **the waste disposal facility in the Manche district and LILW-SL disposal facility in the Aube district.**

No waste has been taken to the Manche disposal facility since 1994; it is currently in the monitoring phase. The Aube disposal facility has been in use since 1992, in the municipality of Soulaines-Dhuys *(see special report 4).*

Laboratory waste (LILW-SL)

Very-low-level waste (VLLW)

VLLW waste comes mainly from dismantling of nuclear facilities or from conventional industries using naturally-occurring radioactive materials. It usually takes the form of inert waste (concrete, rubble, earth) or metal waste.

Production levels of this waste will increase considerably due to large-scale dismantling of the nuclear power plants currently in operation, or fuel cycle facilities and research centres. The level of radioactivity of this waste is less than 100 becquerels per gram.

This waste is disposed of at the VLLW disposal facility located in the municipality of Morvilliers (Aube district) and put into service in August 2003 *(see special report 4)*.

Very short-lived waste

Some waste, mainly hospital waste, contains very short-lived radionuclides (with half-lives of less than 100 days) that are used for diagnosis or therapeutic purposes. Due to their very short half-lives, this waste is stored on the sites of use, for a few days or up to several months, until its radioactivity has decayed. It is then disposed of by the same procedures as conventional waste.

Classification of radioactive waste

<table>
<tr><th colspan="4">HALF-LIFE</th></tr>
<tr><th>ACTIVITY</th><th>Very short-lived
Half-life < 100 days</th><th>Short-lived
Half-life ≤ 31 years</th><th>Long-lived
Half-life > 31 years</th></tr>
<tr><td>Very low level
(VLL)</td><td rowspan="3">Stored to allow radioactive decay on the production site
then disposed of adopting conventional solutions</td><td colspan="2">Surface disposal facility
(Very-low-level radioactive waste disposal facility in the Aube district)</td></tr>
<tr><td>Low level
(LL)</td><td rowspan="2">Surface disposal facility
(Low-and intermediate-level waste disposal facility in the Aube district)</td><td>Shallow disposal facility
(studied in accordance with the Act of 28 June 2006)</td></tr>
<tr><td>Intermediate level
(IL)</td><td rowspan="2">Reversible deep geological disposal facility
(studied in accordance with the Act of 28 June 2006)</td></tr>
<tr><td>High level
(HL)</td><td></td><td></td></tr>
</table>

1.3

It should be noted that there is no single classification criterion enabling the category of waste to be determined: as well as the overall radioactivity of the waste, it is necessary to examine the radioactivity of each of the radionuclides in the waste.

Furthermore, this classification, based solely on the level of radioactivity and the half-lives of the radionuclides contained in the waste, is not sufficient to determine with precision the appropriate management method for a given type of waste.

The physical and chemical characteristics of the waste, together with its source, also have to be taken into account.

Moreover, the waste management options can evolve in the light of advances in knowledge of waste at the time of its recovery or dismantling of facilities, together with the progress made in studies concerning optimisation of treatment and conditioning methods.

1.3 Special cases

Certain types of waste are dealt with using specific management methods, due to their characteristics.

1.3.1 Waste with technically-enhanced radioactivity

Waste with technically-enhanced naturally occurring radioactivity (TENORM) is waste **generated by transformation of raw materials that naturally contain radionuclides** and that are not used for their radioactive properties.

This type of waste is not a product of nuclear activities. It consists mainly of waste from the chemical or metal production industries (phosphate fertilisers, rare earth elements, zircon sands, etc.).

For these particular types of waste, and within a strict framework, the circular of 25 July 2006 [IV] provides the possibility of specific management through acceptance in a conventional waste disposal facility.

For example, this can take the form of disposal of products from demolition of old factories, equipment, or process residues.

Their management procedures and their inventory are set out in *special report 3*.

1.3.2 Waste without a specific disposal solution

It is sometimes impossible to classify certain types of waste in a particular category, either because they cannot be accepted in the existing disposal facilities in the light of some of their characteristics, and especially their chemical characteristics, or because the treatment or conditioning processes are unavailable or particularly complex to develop with regard to volumes that can be small at times.

Examples include oils and organic liquids, waste containing asbestos, or waste containing mercury.

In conformity with the requirements set out in the PNGMDR, a working group has been set up for the period until 31 December 2012, to define management procedures that are suitable for the particular physical or chemical aspects of these types of waste for which there is currently no specific disposal solution.

Depending on the working group's conclusions, these types of waste could be included in one of the solutions defined above, or they will have to undergo suitable treatment.

1.3.3 Waste concerned by a legacy management method

The management procedures for radioactive waste have evolved over time.

In most cases, the mining waste listed in the *National Inventory* has been **disposed of definitively on or near the former mining sites** *(see chapter 4)*.

Other types of waste have been managed near the production sites and used as backfill *(see chapter 4)*. Lastly, **waste has been dumped at sea by various European countries.** This dumped waste is shown in *special report 1*.

[IV] *Circular of 25 July 2006 BPSPR/2006-217/HA.*

1.4
General principles of radioactive waste management

1.4.1
Management policy

The principles governing management of radioactive waste are set out in a strict regulatory framework defined at national and international levels. In particular, **France is a signatory of the Joint convention on the safety of spent fuel management and on the safety of radioactive waste management,** drawn up under the aegis of the IAEA [V], which sets out management principles. These management principles have now been transposed at European and national levels.

At the European level

On 19 July 2011, the European Council adopted a directive [VI] setting up a European framework for safe, responsible management of spent fuel and radioactive waste, from their production to their disposal.

It thus supplements the Euratom legislative instruments that did not cover the subject. The directive covers all the stages of management of spent fuel and radioactive waste resulting from civil activities. Each Member State bears final responsibility for management of the spent fuel and radioactive waste generated on its territory.

The directive requires each Member State to draw up and update a national framework that covers setting up of national programmes for management of spent fuel and radioactive waste, granting licences, drawing up inventories, steps to provide monitoring and inspections, execution measures such as suspending operation, a breakdown of responsibilities, information and participation of the general public, and financing. Furthermore, the directive requires each Member State to set up and maintain a regulatory authority competent for management of spent fuel and radioactive waste, setting out certain conditions to ensure the authority's independence.

1.4

At the national level

France has defined and implemented a determined public policy covering radioactive waste, within a legislative framework set up in 1991 (Act of 30 December 1991 [VII]) and consolidated in 2006 (Act of 28 June 2006 [I]). Priority was given to the solution involving disposal of ultimate radioactive waste, and this is set out in the act.

Disposal occurs after treatment of spent fuel or conditioning of the waste, and storage where applicable.

The policy is managed by the Energy and climate Directorate-General (DGEC) in the Energy ministry, and it is based on three main elements:

- a National plan for management of radioactive materials and waste (PNGMDR) [VIII], which is updated once every three years by the French government and sets out a research and execution programme, with a schedule;
- provisions covering independent evaluation of research, information for the general public and dialogue with all the stakeholders;
- guarantees covering availability of the financing necessary under article L. 110-1 of the Environment Code, which states that **"the expenses arising from the steps taken to ensure prevention, reductions in pollution and efforts to prevent pollution, are borne by the polluting entity",** it is up to the producer of the waste to finance its long-term management.

[V] *Joint convention on the safety of spent fuel management and the safety of radioactive waste management, available at: www-ns.iaea.org/conventions/waste-jointconvention.asp*
[VI] *New European Council directive 2011/70/Euratom of 19 July 2011 relative to management of spent fuel and radioactive waste.*
[VII] *Act 1,381 of 30 December 1991 on research on management of radioactive waste.*
[I] *Planning Act 2006-739 of 28 June 2006 on long-term management of radioactive materials and waste.*
[VIII] *PNGMDR (National plan for management of radioactive materials and waste), available on the site www.developpement-durable.gouv.fr/Le-plan-national-de-gestion.html*

French law

Article L. 541-1 of the Environment Code sets out as principles prevention or reduction of waste production, the producers' responsibility until removal of their waste, traceability and the necessity of informing the general public.

For radioactive waste, the Environment Code as amended by the Act of 28 June 2006 states that **"long-term management of radioactive materials and waste of all types, resulting in particular from operation or dismantling of facilities using radioactive sources or materials, is carried out in compliance with the requirements covering protection of human health, safety and the environment"** (article L. 542-1).

Numerous provisions are implemented to comply with this legislative framework:

- provisions concerning treatment and conditioning, transport and facilities: they are defined by the competent authorities, which subsequently monitor their application;
- provisions to reduce the volume and harmfulness of such waste; then, for the waste generated, operations concerning sorting, treatment, conditioning and characterisation of its radiological contents: they are defined and implemented by the producers of the waste. Research and development studies are often necessary, and they are carried out by various organisations, and especially by the CEA;
- design and construction of storage and disposal facilities showing the required level of safety. This concerns either storage (a temporary solution) for which the operators and waste producers are usually responsible, or disposal (a definitive solution) which comes under Andra's responsibility *(see special report 4)* ;
- operations involving transport and storage or disposal, covering the monitoring and supervising aspects, including long-term monitoring for disposal;
- provisions covering information for the general public.

1.4.2 Entities involved in radioactive waste management

Institutional framework

- the National plan for management of radioactive materials and waste (PNGMDR) uses the data from the *National Inventory* as a basis for drawing up an overview of the existing management methods, listing the foreseeable requirements as to storage and disposal and determining the objectives to be reached for waste that is not yet covered by a definitive management method.
- the Directorate-General for risk prevention (DGPR), in the French ministry for the Environment, covers the issues of sites polluted by radioactivity *(see chapter 4)* and sets out the regulations applicable to ICPEs (Facilities classified for protection of the environment) including conventional waste disposal facilities.
- concerning the scientific questions in general, and those related to nuclear programmes in particular, the French Parliament has set up its own evaluation body: the Parliamentary office for evaluation of scientific and technological choices (OPECST). This body holds hearings with the entities dealing with management of radioactive waste and publishes evaluation reports and recommendations, which can be consulted at www.senat.fr/opecst.
- the French Parliament relies on the National Assessment Commission (CNE) which is entrusted with the task of evaluating annually the progress made and the quality of research on management of radioactive materials and waste. The Commission was set up under the French act of 30 December 1991, and confirmed by the French act of 28 June 2006. The Commission publishes an annual report that is submitted to the French Parliament [IX]. The report is published at www.cne2.fr.

[IX] *Reports of the National evaluation committee, available in particular at www.ladocumentationfrancaise.fr/rapports-publics*

• the French National committee for transparency and information on nuclear safety (HCTISN) is a body set up to provide information, consultation and discussions on the risks related to nuclear activities and the impact of such activities on human health, the environment and nuclear safety, set up under the French Act of 13 June 2006 on transparency and safety in the nuclear field (the TSN act) [X]. The HCTISN's reports and recommendations can be consulted at www.hctisn.fr.

• the Nuclear safety authority (ASN), set up under the French Act of 13 June 2006 on transparency and safety in the nuclear field (the TSN Act) is an independent administrative authority.

On behalf of the French State, the authority monitors nuclear safety and radiation protection. It monitors the radioactive waste producers and Andra in their nuclear activities or in activities that require radiation protection measures.

It also examines the licensing procedures for basic nuclear installations (INB), treatment and conditioning facilities and disposal centres for radioactive waste.

It licenses, on an individual basis, the holding of certain radioactive sources or equipment using ionising radiation.

Waste producers

In conformity with book V, title IV, chapter II, article L. 542-1 of the Environment Code as amended by the French act of 28 June 2006, **producers of radioactive waste are responsible for proper management of their waste prior to its removal to a final disposal or recycling location.** In particular, they have to sort the waste and define the methods for treatment and conditioning, depending on the technologies available, with a view to reducing the quantities of radioactive waste and its harmfulness.

They condition the waste, under strict quality assurance procedures as required under the regulations [XI]. They also store radioactive waste for which there is currently no definitive disposal or recycling solution.

Moreover, they are responsible for transport of the conditioned waste to the Andra disposal centres.

For certain producers that do not have suitable resources, due to the small quantities of radioactive waste that they generate, such as research laboratories other than the CEA, or hospitals, Andra usually deals with collection, treatment, conditioning and temporary storage of the waste.

The role of Andra

The National agency for radioactive waste management (Andra) is entrusted with long-term management of French radioactive waste. [I]

It is a public industrial and commercial establishment, set up under the French Act of 30 December 1991. Its missions were extended under the French Act of 28 June 2006.

1.4

[X] *Act No. 2006-686 of 13 June 2006 on transparency and safety in the nuclear field.*
[XI] *Decree of 7 February 2012 setting out the general rules on basic nuclear installations (abrogates the decree of 10 August 1984 on quality of the design, construction and operation of basic nuclear installations).*
[I] *Planning Act 2006-739 of 28 June 2006 on long-term management of radioactive materials and waste.*

Andra is independent of the producers of radioactive waste, and it is placed under the supervision of the French ministries for Energy, the Environment and Research.

Andra is the preferred instrument of the French government for implementation of the radioactive waste management policy. The government sets out Andra's objectives in a four-year contract. Its latest version covers the period from 2009 to 2012. It is available in particular on the Andra Website: www.andra.fr [XII].

Andra places its expertise and know-how at the service of the government to design, operate and monitor radioactive waste disposal facilities, and so protect humans and the environment over the long term from the impact of such waste.

Its mission consists of several activities

1/ **Operating the two existing disposal facilities,** in the Aube district, dedicated to low- and intermediate-level radioactive short-lived waste (LILW-SL) and very-low-level waste (VLLW); **monitoring the Manche disposal facility**, the first French surface-disposal facility for low and intermediate-level radioactive waste, which is now closed;

2/ **Studying and designing long-term management solutions** for waste that does not yet have dedicated disposal facilities:

- disposal of low-level long-lived waste, consisting mainly of radium-bearing waste and graphite waste (LLW-LL project);
- deep reversible geological disposal of high level waste (HLW) and intermediate-level long-lived waste (ILW-LL): Cigéo project (the deep geological repository).

3/ **Managing radioactive waste other than that from nuclear power plants** (generated by hospitals, research laboratories, universities, etc.) and radioactive objects owned by private individuals (old luminescent clocks and watches, objects containing radium for medical use, natural laboratory salts, minerals, etc.).

At the request of the landowner or the public authorities, Andra also deals with **remediation of legacy sites polluted** by radioactivity *(see chapter 4)*.

Andra obtains support from the National committee for aid in the field of radioactivity (CNAR) which issues an opinion on the use of grants from the French government earmarked for missions of general interest, assigned to Andra: cleaning up polluted sites, and dealing with waste.

4/ **Informing the public in general**, particularly by publishing the *National Inventory of radioactive materials and waste* every three years.

5/ **Helping to spread** scientific and technical knowledge through documents, exhibitions, visits to its facilities, etc.

6/ **Passing on its know-how** in France and in other countries.

[XII] *Four-year contract between the French government and Andra, 2009-2012, available at www.andra.fr.*

General results

General results

This chapter sets out overall statements of the declarations made by the producers or holders of radioactive materials and waste during the first half of 2011. In conformity with decree 2008-875 (see chapter 1), these declarations concern:

- *the stocks of materials and waste as at 31 December 2010;*
- *the forecasts concerning materials and waste for 2020 and 2030.*

In contrast to the stocks that have to be declared by all the producers or holders of waste or materials, forecasts are only required for operators of INBs[1], facilities concerning Defence or nuclear ICPEs[2] (sections 1,715 or 1,735 of the ICPE listings).

In all, over 1,200 geographical sites within the meaning of the *National Inventory* *(see appendix 1)* on which radioactive waste was located at the end of 2010 are listed in the 2012 edition.

Although most radioactive waste is generated by the nuclear power industry and the CEA activities, numerous other sectors also generate radioactive waste, such as industries other than nuclear power, Defence, research outside the nuclear field, or the medical sector. In spite of their large numbers, these "small-scale nuclear activities" waste producers only account for a small proportion of the volume of radioactive waste in France.

Details of the sites listed are to be found in the Geographical Inventory, available separately.

In its first part, this chapter provides a quantitative overview of the existing radioactive waste at the end of 2010 and the waste that will be generated by 2020 and 2030. The forecasts are based on an assumption of ongoing nuclear power production and continuation of the French policy for management of spent fuel at least until the latter date. The only radioactive waste evaluated is that stemming from facilities (due to their operation and dismantling) for which the construction licence is dated on or before 31 December 2010.

In the second part of this chapter, a list of the radioactive materials expected by 2020 and 2030 is also set out.

Lastly, a forward-looking view of the waste and materials likely to be generated by all the facilities licensed as at the end of 2010 until the end of their service life is included at the end of the chapter. These evaluations are set out on the basis of two deliberately contrasting energy scenarios.

The scope of the waste taken into account in the statements presented

The radioactive waste taken into account for the statements set out in this chapter is that which is to be dealt with by Andra in disposal facilities dedicated to management of such waste. The other waste, which has been dealt with using "legacy" management methods, is shown, and its quantities are evaluated separately in a specific chapter:

- **residues from treatment of uranium ores** that are disposed of on certain former mining sites. The *National Inventory* lists 20 sites on which the residues are disposed of *(see chapter 4)* ;
- **the waste "disposed of *in situ*"** that was disposed of in the past close to nuclear facilities or plants. It usually takes the form of mounds, backfills or lagoons *(see chapter 4)* ;
- **waste dumped at sea** *(see special report 1)*.

2.

1 *INB: Basic nuclear installation.*
2 *ICPE: Facility classified for protection of the environment.*

Furthermore, the following are not quantified:

- radioactive substances located on sites that have accommodated activities involving handling of radioactivity. These polluted sites are set out in *chapter 4*;
- very short-lived (VSL) waste that is managed on site during its decay period and then disposed of by conventional methods. This waste is not sent to a radioactive waste disposal facility.

Lastly, the waste generated by the COMURHEX plant in Malvési (Aude district) is shown separately: at the end of 2011, under the PNGMDR, AREVA submitted a study concerning long-term management of this waste. The study is being examined. Pending a decision concerning the method for long-term management of this waste, the family is shown separately in the statements setting out figures for the stocks of waste existing at 31 December 2010, and in the forecasts. Most of this waste is stored in settling and evaporation ponds, so it is not conditioned.

These exclusions concern all the statements set out in chapters 2 and 3. They are not mentioned again below.

2.1 Radioactive waste as at the end of 2010

The volumes of radioactive waste listed correspond to the volumes of waste conditioned so that it can be stored and transported to a disposal facility, making up what are known as primary packages.

The volume units used

The unit adopted to draw up the statements is the **"conditioned equivalent volume".** This enables us to use a uniform accounting unit for all the waste. The forecasts also use the same unit.

For waste whose conditioning is not yet known, assumptions are made to evaluate the conditioned equivalent volume.

For deep underground disposal, further conditioning known as a disposal package is necessary to provide the handling, safety or reversibility functions. At this stage of the studies, the volume of the disposal packages as compared with the volume of the primary packages represents a factor of the order of two or three for HLW waste and a factor of the order of four for ILW-LL waste. **Only the primary volume is given in this document.**

In this chapter, the radioactive waste generated and the future estimates are shown by source.

Five economic sectors are defined as follows:

- **the nuclear power sector** which is mainly made up of the nuclear power plants, together with the plants dedicated to production and treatment of nuclear fuel (extraction and treatment of uranium ore, chemical conversion of uranium concentrates, fuel enrichment and manufacturing, spent fuel processing and recycling) *(see box on page 26)*;
- **the Defence sector**
This mainly covers activities linked to the nuclear deterrent weapons, including the nuclear propulsion systems of certain ships and submarines, together with the corresponding research activities;
- **the research sector** which includes research in the civil nuclear field, research laboratories in the medical, particle physics, agronomics, chemistry sectors, etc.;
- **the industry sector (excluding nuclear power)** which includes in particular extraction of rare earth elements, and manufacture of sealed sources, together with various applications such as welding inspections, sterilisation of medical equipment, sterilisation and preservation of foodstuffs, etc.;
- **the medical sector** which includes therapeutic, diagnosis and research activities.

The nuclear fuel cycle [I]

Current fuel cycle

To enable their use in a nuclear reactor, radioactive materials must go through a fuel cycle made up of several stages, before and after their irradiation in a reactor.

Before irradiation

The uranium ore, extracted from mines, must first be concentrated and then converted chemically. It then has to be enriched to increase the proportion of uranium-235, which is too low in natural uranium. In parallel, the process also results in a flow of uranium that is depleted in uranium-235, which is stored with a view to subsequent use. The fuel as such can then be made using the enriched uranium.

Irradiation

To generate electricity, the fuel is then irradiated in a reactor for about three or four years.

After irradiation

At the end of this stage, 96% of the fuel still contains large quantities of potential energy (uranium and plutonium). 4% of the fuel can no longer be recovered, and is waste.

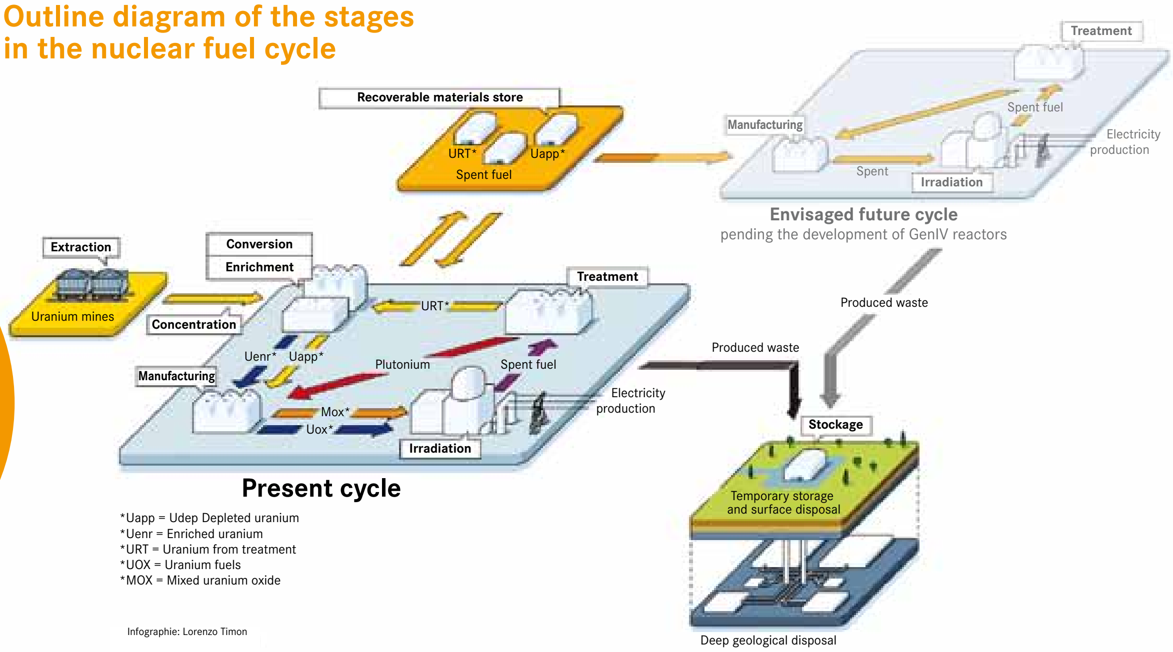
The processing operation for spent fuel enables extraction of valuable materials for recycling. Plutonium is recycled in the form of a fuel known as MOX, which also incorporates depleted uranium, and which can then be irradiated in certain French reactors. The uranium recovered from the treatment sequence can be re-enriched for subsequent renewed irradiation in certain French reactors. The treatment operation also enables conditioning of the waste from the spent fuel. This waste, which contains most of the radioactivity from spent fuel, is set aside for definitive disposal (reversible deep geological underground disposal currently being studied: *see special report 4*).

Future fuel cycle

Another fuel cycle, on which research is being carried out at the moment, could enable future use of the quantities of depleted uranium, processed uranium and spent fuel currently stored for possible recycling. This cycle would include in particular what are known as 4th generation reactors. This cycle would also generate radioactive waste.

2.1

Outline diagram of the stages in the nuclear fuel cycle



[I] *Source: PNGMDR 2010-2012 – Synthesis.*

The volume of radioactive waste (other than waste from the COMURHEX plant in Malvési, in the Aude district) listed from the beginning of its production up to 31 December 2010, is about **1,320,000 cu. m** (conditioned equivalent volume), i.e. about 170,000 cu. m more than at the end of 2007.

72% of this waste is already definitively disposed of in the Andra facilities: the VLLW waste is at the VLLW disposal facility (Aube district) and the LILW-SL waste at the CSM disposal facility (Manche district) and at the LILW-SL disposal facility (Aube district). The remaining is stored on the producers' sites in facilities dedicated to the purpose. It consists of the following:

- for the waste to be taken to the existing facilities:
  - storage in the form of packages, of a logistical nature, enabling management of the flows towards the Andra facilities,
  - storage of waste, especially legacy waste, awaiting conditioning and subsequent removal;
- for the waste to be taken to the planned sites:
  - storage until such time as disposal solutions are made available;
  - for high-level waste, this entails storage for several decades in decay storage to cool down, before it can be placed in deep underground disposal facilities.

The types of waste, the quantities stored and the storage locations are set out in the Geographical Inventory.

2.1.1 Breakdown of waste by category at the end of 2010

Stocks at the end of 2010

The volumes of radioactive waste in France at the end of 2010, other than waste from other countries *(see box on page 28)*, are shown in the table and chart below.

In the table, the volumes are compared with those at the end of 2007 (2009 edition of the *National Inventory*).

Category	**Volume*** (conditioned equivalent cu. m) at the end of 2010	**Difference for 2010 - 2007** (conditioned equivalent cu. m)
HLW	2,700	400
ILW-LL	40,000	-2,000
LLW-LL	87,000	4,500
LILW-SL	830,000	37,000
VLLW	360,000	130,000
DSF**	3,600	2,100
Total général	**~ 1 320,000**	**~ 170,000**

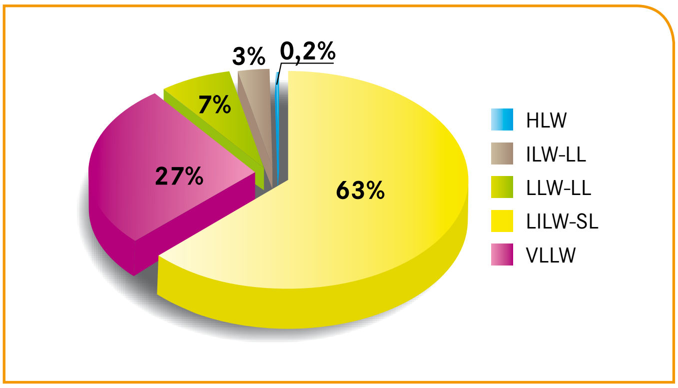
** The figures are rounded to the nearest hundred cu. m for the HLW and the waste without disposal solutions, and the nearest hundred or thousand cu. m for the other waste.*
*** The waste without disposal solutions (DSF) accounts for less than 0.3% of the total volume of waste, and is not shown in the chart below.*

Concerning the waste from the COMURHEX plant in Malvési (Aude district), whose long-term management method is currently being defined *(see page 25)*, the statement is as follows:

Category	**Volume*** (cu. m) **at the end of 2010**	**Difference for 2010 - 2007** (cu. m)
UCTR***	600,000	600,000

**** Uranium Conversion Treatment Residues.*

Breakdown by volume per waste category



The volumes shown in the *table on page 27* are based on a certain number of assumptions, set out in detail in the Catalogue describing the waste families. The main assumptions are as follows:

- for non-conditioned waste, the conditioning assumptions adopted for the statements are those made by the producer, even though some of the assumptions are still being studied and/or have not yet been validated by the Nuclear safety authority or accepted by Andra with a view to disposal;
- the waste from dismantling operations is included if the dismantling operation has effectively been completed as at 31 December 2010.

Thus the LLW-LL graphite waste that is still in the GCR reactors (reactor stacks, reflectors in place, support areas) is not included in the stocks at the end of 2010 but it is taken into account in the forecasts concerning volumes of waste, depending on the actual dismantling date *(see page 40)* ;

- when studies concerning the management solutions for a particular family of waste are still under way, the family is classified in accordance with the assumption made by the producer. Andra checks the proposed classification. The choice of category does not entail acceptance of the waste at a disposal facility;
- part of the waste on the site of the AREVA NC plant at La Hague (Manche district) is to be sent back to customers in other countries. This means that the waste from other countries as referred to in article L. 542-2-1 of the Environment Code is not taken into account in the statements;
- spent sources other than lightning conductors (sealed sources, smoke detectors, source rods, source clusters, etc.) are included in a special family that is not linked to the waste classification management solutions, except for the legacy packages stored at Cadarache (Bouches-du-Rhône district) ("source block" ILW-LL packages). In this *National Inventory*, no conditioned equivalent volume is allocated to these sources, due to the variability of the management and conditioning assumptions possible at this stage. The lightning conductors are assigned to two families of LLW-LL type waste. *Special report 2* contains a list of these sources and lightning conductors.

Waste from outside France

France has adopted the principle of banning disposal in France of radioactive waste from other countries. The principle was introduced into French law in 1991, taking into account the industrial activities concerning processing of spent nuclear fuel or radioactive waste, and it was reaffirmed and set out in greater detail in the act of 28 June 2006.

The French nuclear industry has developed a unique technology for processing spent fuel, in order to remove the materials that can be recovered (uranium and plutonium) for other nuclear power uses and separate out the ultimate waste for disposal.

This technology, applied to the French nuclear cycle, was opened up by the CEA (now AREVA) in the 1970s (under contract) to electricity companies in other European countries and Japan. Since 1977, the CEA (now AREVA) has included in all its contracts a clause enabling the ultimate waste from processing of their fuel to be returned to these foreign customers for disposal.

Since promulgation of the 2006 act, to enable control of application of these provisions, the operators concerned have to draw up an annual report setting out the stocks and the flows of radioactive substances from and to other countries, and the report must include a prospective section. The reports are published, and they are shown in *appendix 2*.

2.1

Changes since the 2009 edition

The differences noted between the amounts of waste generated at the end of 2007 and those generated at the end of 2010 are mainly due to the current production of waste.

The differences are also due to the following factors:

- optimisation of the volume of the conditioning envisaged for certain types of waste, resulting in a reduction in the volume of ILW-LL waste;
- additional characterisation of the Marcoule (Gard district) bitumens enabling the waste to be redirected from the ILW-LL procedure to the LLW-LL procedure, which results in an increase in the LLW-LL waste;
- a significant increase in the volume of VLLW waste due to more stringent clean-up targets for the civil engineering structures of the facilities dismantled.

The radioactive waste in France at the end of 2010 is described briefly in the *boxes on pages 31 and 32*. A summary of the main changes for each management system as compared with 2007 is set out below.

For the HLW waste (high-level)

The changes in stock levels of HLW waste at the end of 2010 correspond to the current production of vitrified waste from solutions of fission products, stemming from processing of spent fuel at the AREVA NC plant at La Hague (Manche district).

Concerning the spent fuel that is to be conditioned for direct disposal in Cigéo instead of being processed, only the spent fuel from the prototype heavy water reactor at Brennilis (Finistère district) is considered as waste. Other spent fuel (fuel from the CEA research reactors, some fuel from GCR reactors that has not been processed, etc.) was considered as waste in the 2009 edition. Fresh assumptions concerning management of this irradiated fuel have led the CEA to consider it as recyclable materials in this edition *(see page 48)*.

For the ILW-LL waste (intermediate-level long-lived)

In spite of three more years of current production of ILW-LL waste, the volume in stock at the end of 2010 fell by about 5% as compared with the stocks at the end of 2007, as set out in the 2009 edition.

The fall is mainly due to the following factors:

- optimisation of the conditioning of the sludge generated by operation of the UP2-400 plant at La Hague (Manche district) before 1991 and stored in seven silos from the former effluent treatment station (STE2). The alternative process to bituminisation, which was initially adopted to condition the sludge, has led to a decrease in volume of about 1,500 cu. m;
- moreover, certain types of waste classified as ILW-LL in the 2009 edition have been transferred to the LLW-LL or LILW-SL categories, thanks to further characterisations. As an example, we can mention part of the powder waste stored in silos at the La Hague plant (Manche) whose volume has been reduced by about 350 cu. m;
- other changes have been noted in the conditioning assumptions adopted by the producers of radioactive waste; they could lead to reductions or increases in volume. For example, optimisation of the conditioning of solid waste from CEA operation in 870-litre packages has led to a fall of about 500 cu. m in the total volume of this waste family.

For the LLW-LL waste (low-level long-lived)

The volume of the LLW-LL waste has risen by about 4,500 cu. m since the previous edition of the *National Inventory*.

The big increase is mainly due to the following reasons:

- the new assumptions adopted by the CEA for conditioning the LLW-LL category drums of bituminised waste from Marcoule (Gard district) lead to an increase of about 6,000 cu. m in the total volume;
- the conditioning of the graphite sleeves stored in ponds at Marcoule (Gard district) has been optimised, resulting in a reduction in volume of the order of 3,000 cu. m;

- the process initially studied for recycling of the silos of the plant at La Hague (Manche district) containing graphite sleeves and GCR fuel cladding waste featured sorting the waste from the silos. The process has now been abandoned due to its complexity: the waste from the silos will be crushed and conditioned in drums, immobilised by a cement matrix. The new process leads to an increase of 500 cu. m;
- in the same way, the modifications made to conditioning for the waste from the bottoms of silos or settling systems at the plant in La Hague (Manche district) and the reclassification of certain types of waste for the LLW-LL disposal facility lead to an increase in volume of about 1,000 cu. m.

For the LILW-SL waste (low and intermediate-level short-lived)

The increase in the volume of LILW-SL waste at the end of 2010 is mainly due to the three extra years of operation of the reactor units. Other changes such as transfers of waste from other categories have also led, to a lesser extent, to an increase in the volume of stocks for the category.

For the VLLW waste (very-low-level)

By comparison with the figures as at the end of 2007, we note an increase of about 130,000 cu. m in the volume of VLLW waste at the end of 2010; this increase is greater than expected (about 75,000 cu. m) corresponding to the planned operation of the VLLW disposal facility.

2.1

One of the reasons for the sharp increase is the application to the dismantling and clean-up operations of the new ASN guide concerning the acceptable full clean-up methodologies for INBs in France [II].

The more stringent requirements as to the clean-up objectives have led to classification in the VLLW category of the waste from cleaning up the civil engineering structures of facilities to be dismantled, which was previously taken to standard waste disposal facilities.

For the waste without disposal solutions (DSF)

An item of waste without disposal solutions is defined by convention as an item of waste that cannot currently be included in any of the existing or planned disposal solutions, mainly on account of its specific physical or chemical characteristics. Moreover, this waste has been qualified as "without disposal solutions" in the current state of our knowledge. As that knowledge is evolutive by nature and the hazard levels are assessed mainly on the basis of feedback from experience, the conditions of acceptance can change over time. Thus certain types of waste that are currently considered as not having any disposal solutions could subsequently come under one of the various categories of waste management.

The studies carried out under the 2010-2012 PNGMDR by the "waste without disposal solutions" working group have provided further details concerning the inventory of this type of radioactive waste. At the end of 2010, its volume stood at 3,600 cu. m:

- waste containing asbestos: 1,700 cu. m;
- waste containing mercury: 300 cu. m;
- metal mercury: 6.2 tonnes;
- oils and organic liquids that cannot be incinerated: less than 600 cu. m;
- miscellaneous (for which management proposals are currently being studied): about 1,000 cu. m.

The ongoing characterisation of these types of waste in particular will enable disposal solutions for them to be defined.

For the waste generated by the COMURHEX plant at Malvési in the Aude district (uranium conversion treatment residues family - UCTR)

Under the PNGMDR, at the end of 2011 AREVA submitted a study covering long-term management of this waste. The study is currently being examined. Until such time as a decision is made concerning the long-term management methods for this waste, this family is presented separately.

It includes:

- nitrate solutions (~321,000 cu. m);
- sludge from settling (~280,000 cu. m).

To which it may be necessary to add 200,000 to 300,000 cu. m of mining tailings and sludge contaminated at levels of over one becquerel per gram.

In the previous edition of the *National Inventory*, these types of waste were included in the family of uranium treatment residues from former mining sites, so they were not shown in the statements.

[II] *Memorandum ASN SD3-DEM-02 of 27 March 2006 and then draft ASN guide No. 14 of 21 June 2010.*

HLW waste

The high-level waste corresponds mainly to the vitrified waste resulting from processing of spent fuel. It consists of fission products and minor actinides formed during nuclear reactions in the fuel and separated out from uranium and plutonium, the recoverable radioactive materials, during processing. They are calcinated and incorporated in a glass matrix. The glass thus obtained is poured at high temperature into a stainless steel container.

Vitrification has been developed in several pilot facilities operated by the CEA, including the PIVER pilot facility that has now been decommissioned, and then implemented on an industrial scale in the following three units: Marcoule (Gard district) vitrification plant, which was commissioned in 1978, and vitrification units R7 and T7 in the AREVA NC plant at La Hague (Manche district), which were commissioned in 1989 and 1992 respectively.

This category also includes the **spent fuel** from the Brennilis heavy water reactor in Finistère district (27 cu. m) which has not been heated.

ILW-LL waste

The ILW-LL waste corresponds mainly to the structural elements from the spent fuel processing, residues from treatment of the effluents generated during the fuel treatment stages or from maintenance or dismantling operations concerning facilities, components (other than fuel) that have been used inside reactors (activated waste), and waste stemming from routine maintenance operation and/or dismantling of units, laboratories, etc. (technological waste).

Five main processes have been, are or will be implemented to package these types of waste:

- **vitrification:** a process implemented mainly to condition the effluents generated when facilities are rinsed prior to dismantling;
- **bituminisation:** process very commonly used in the past to condition effluents treated on the various sites. It is gradually being replaced by cementation or vitrification;
- **cementation:** the most widely used process for conditioning residues stemming from treatment of effluents;
- **embedding of solid waste** in a cement matrix: the purpose of this process is to immobilise solid waste such as technological, activated or cladding waste inside a container;
- **compacting:** process used above all to condition structural waste stemming from the spent fuel processed on the AREVA NC site at La Hague (Manche district), together with certain types of technological, activated or structural waste from the CEA.

LLW-LL waste

LLW-LL waste covers three main types of waste: graphite waste, radium-bearing waste and other LLW-LL waste such as spent sealed sources or bituminised waste packages.

- **graphite waste** comes mainly from operation and dismantling of French reactors using the gas-cooled graphite-moderated (GCR) process, certain experimental and production plutonium reactors. Operation of the GCR process led to use of large quantities of graphite as a neutron moderator. Two types of waste were generated by these reactors: operating waste (the sleeves surrounding the fuel), which is currently stored on the sites at La Hague (Manche district), Marcoule (Gard district) and Saint-Laurent-des-Eaux (Loir et Cher district), in some cases mixed with other waste, and dismantling waste (the stacks that made up the reactor cores and biological protections). These types of waste are described in the Catalogue of families.
- **radium-bearing waste** comes from the industries using radium and its derivatives, and from treatment of ores. In fact, it consists mainly of residues from treatment of uranium ores by the CEA and treatment of other ores (such as monazite) by the chemicals industry. A smaller proportion of this waste corresponds to earth and rubble removed during work to clean up sites on which radium was formerly processed. Up to now, very little of that radium-bearing waste has been conditioned. Studies are currently under way concerning conditioning and near-surface disposal of such waste.
- **the other LLW-LL waste** corresponds to waste whose level of activity and radionuclides prevent its disposal in the existing disposal facilities. It consists in particular of spent sealed sources, lightning conductors containing radium, or americium collected by Andra *(see special report 2)* together with certain bituminised waste packages from the CEA.

VLLW waste

VLLW waste comes mainly from dismantling and clean-up operations or maintenance activities.

It consists of concrete, rubble, earth, and metal or non-metallic waste.

Depending on its nature, the waste is conditioned in big bags or put in metal boxes.

Any chemically hazardous waste is made inert prior to disposal, usually by cementation.

LILW-SL waste

This corresponds to waste coming from treatment of liquid effluents and process waste from ordinary operation and maintenance of nuclear facilities. It also stems from dismantling of units.

This category also includes the waste from the "small-scale nuclear activities" waste producers that correspond to hospitals, laboratories, research centres, etc., residues from waste incineration and melting, together with very large items of waste such as reactor vessel heads. The conditioning process implemented is mainly cementation in metal or concrete containers.

However, some types of process waste or residues from treatment of effluents can be embedded in polymer or bituminised matrices.

T-LILW-SL waste

This consists of tritiated low and intermediate-level short-lived (T-LILW-SL) waste. Although tritium is a radionuclide with a short half-life, it is difficult to confine and it can easily migrate into the environment and mark it. Most tritiated waste is solid; the very small quantities of liquid and gaseous waste have to be treated and stabilised before storage. After about fifty years of storage, the waste is taken, depending on its level of radioactivity and the residual gas release rate, to the very low level waste disposal facility or the low and intermediate level, short-lived waste disposal facility that Andra operates in the Aube district.

2.1

2.1.2
The waste stored at the end of 2010

Storage of radioactive materials or waste is defined in the French Act of 28 June 2006 as **"the operation consisting in placing the substances on a temporary basis in a surface or near-surface facility specially developed for the purpose, until such time as they are to be recovered"** to condition them if necessary and dispose of them. Article 3 of the decree of 9 October 2008 requires producers to declare to the *National Inventory* a certain number of items of information concerning storage of HLW and ILW-LL waste packages intended for deep disposal, produced or to be produced, for radium-bearing waste and tritiated waste.

Moreover, under the 2010-2012 PNGMDR, Andra was entrusted with the task of submitting at the end of 2012 a report summing up all the studies and research concerning storage, in particular to ensure that there is sufficient storage capacity available until such time as the HLW, ILW-LL and LLW-LL disposal facilities are commissioned. The operators usually assign a planned service life of about fifty years to the existing storage sites.

Furthermore, extensions to these storage sites are planned to meet the needs evaluated by the producers. The *table on page 34* lists these licensed storage sites as at the end of 2010, with their levels of occupation for the sites in use; the *table below* shows the planned extensions for some of the storage sites.

Storage building at the AREVA NC R7 UP2 800 vitrification unit at La Hague (Manche district)

Planned extensions for storage sites

Declaring entity	Site	Waste packages for which the storage site is designed	Date of commissioning of the extension	Total storage capacity (number of packages)
AREVA NC	EEV/LH (La Hague - Manche)	CSD-V, CSD-B packages	2013 and 2017	8,424
CEA	EIP (Marcoule, Gard)**	Bituminised sludge packages	2017	4,235*
CEA	INB 164-CEDRA (Cadarache, Bouches du Rhône)	500 l and 800 l packages, 500 l concrete packages for filtration sludge	2020	7,500*
CEA/DAM	Storage of tritiated waste (Valduc, Côte d'Or)	Tritiated waste	2012	15,000

** Capacity shown in cu. m.*

*** The CEA reference scenario is conditioning at Marcoule (Gard district) of ILW-LL waste in disposal packages as from 2017, followed by intermediate storage prior to shipment to Cigéo when commissioned. A backup scenario plans for opening of an extension of the EIP storage facility early in 2017.*

Storage sites licensed as at the end of 2010

Declaring entity	Site	Waste packages for which the storage site is designed	Date of commis-sioning	Total storage capacity (number of packages)	Storage capacity in use (number of packages)	Level of use
AREVA NC	CEZUS (Jarrie - Isère district)	Drums of radium-bearing residues	2005	3,538*	1,946*	55%
AREVA NC	ES building (La Hague - Manche district)	Bituminised sludge packages	1995	27,000	0	0%
AREVA NC	S building (La Hague - Manche district)	Bituminised sludge packages	1987	20,000	11,278	56%
AREVA NC	ECC (La Hague - Manche district)	CSD-C packages	2002	20,800	10,270	49%
AREVA NC	EDS/ADT2 (La Hague - Manche district)	CBF-C'2 packages	2008	2,759	451	16%
AREVA NC	EDS/EDC-A (La Hague - Manche district)	Cemented hull and end cap packages	1990	1,119	149	13%
AREVA NC	EDS/EDC-B and EDC-C (La Hague - Manche district)	Cemented hull and end cap packages	1990	1,656	1,518	92%
AREVA NC	EDS/EDT (La Hague - Manche district)	CBF-C'2 and CAC packages	1990	6,512	4,538	70%
AREVA NC	EEV/SE (La Hague - Manche district)	CSD-V and CSD-B packages	1996	4,320	3,733	86%
AREVA NC	R7 (La Hague - Manche district)	CSD-V and CSD-B packages	1989	4,500	4,057	90%
AREVA NC	T7 (La Hague - Manche district)	CSD-V packages	1992	3,600	3,153	88%
CEA	ICPE 420 and 465 - RHODIA waste (Cadarache - Bouches-du-Rhône district)	Drums of radium-bearing residues	1992	26,800	25,327	95%
CEA	INB 164-CEDRA (Cadarache - Bouches-du-Rhône [3] district)	500l and 870l packages, 500l concrete packages filtration sludge	2006	7,500*	935*	12%
CEA	INB 56 (Cadarache - Bouches-du-Rhône district)	Miscellaneous packages	1968	7,500*	6,833*	91%
CEA	AVM (Marcoule - Gard district)	Vitrified waste packages (AVM), AVM operating waste packages	1978	665*	584*	88%
CEA	EIP (Marcoule - Gard district)	Bituminous sludge packages	2000	4,235*	3,069*	72%
CEA	PIVER (Marcoule - Gard district)	PIVER glass	1976	46*	13*	28%
CEA/DAM	Tritiated waste storage unit (Valduc - Côte-d'Or district)	Tritiated waste	1982	15,500	13,600	91%
EDF	ICEDA (Bugey - Ain district)	Cemented packages	2014	2,000	0	0%
RHODIA (La Rochelle)	Chef-de-Baie plant (Charente-Maritime district)	Radium-bearing waste	1988	56,980*	7,580*	13%

Capacities shown in cu. m.

2.1

[3] *The facility is not licensed to accept other types of packages.*

2.1.3
Radiological content of the radioactive waste at the end of 2010

Concerning **VLLW and LILW-SL waste,** the producers declare the radioactivity levels of each of the packages, at the time of sending them to the disposal facilities.

The radioactivity levels are estimated using a method based on measurements and/or evaluations using calculations.

After checking conformity, Andra authorises their disposal. Apart from a few exceptions, the levels of the waste shown in the Catalogue of families are evaluated on the basis of the declarations, which have been kept since the sites were put into service.

In the case of **HLW and ILW-LL waste,** the radioactivity is measured during production of the waste packages. Concerning the legacy waste awaiting conditioning, samples are analysed to estimate the radioactivity levels of the legacy waste. They will be checked in greater detail when the waste is recovered.

To simplify management, the waste radioactivity levels declared by the producers are those at the date of production, and they do not take the natural decay of the radionuclides into account. They are thus bound to be higher than the actual current levels. The values are those shown in the Geographical Inventory.

Due to radioactive decay, the radioactivity levels currently present in the waste are lower than those declared at its production date.

Andra sets out in the summary on this page, and also in the Catalogue of families, the values that result from calculations concerning radioactive decay up to the end of 2010. The calculations are made by Andra on the basis of the data supplied by the producers *(see appendix 3)*.

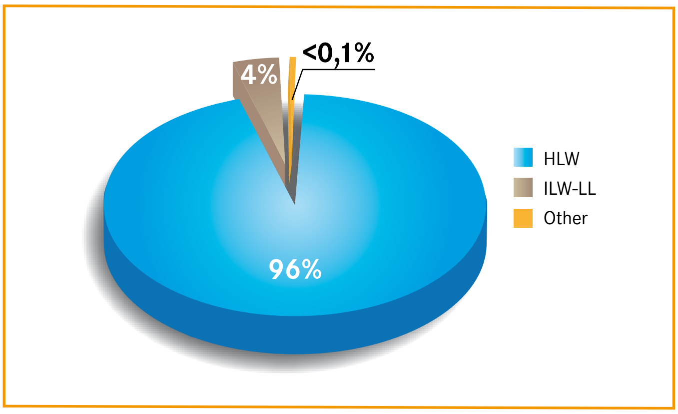
The table and chart sum up the total radioactivity of the stocks of waste.

Evaluated radioactivity levels at 31 December 2010

Category	Radioactivity at the end of 2010 in TBq (10^{12} Bq)
HLW	105,000,000
ILW-LL	4,800,000
LLW-LL	12,000
LILW-SL	27,000
VLLW	5
UCTR	100*
Total	**~ 110,000,000**

** Declared radioactivity level.*

Breakdown of the radioactivity levels by category



The total radioactivity declared by the producers is of the order of 200 million terabecquerels, whereas the level estimated by Andra at the end of 2010 is of the order of 110 million terabecquerels. This considerable difference is due to the fact that radioactive decay is taken into account.

For example, the calculations concerning radioactive decay for a glass package show that its total radioactivity is halved after about 20 years *(see appendix 3)*.

In the radiological content, we can make a distinction between the following 3 types of radionuclides: radionuclides emitting alpha, short-lived beta-gamma and long-lived beta-gamma radiation. The evaluated radioactivity of all the waste generated as at 31 December 2010 is shown in the *table below*.

Evaluated radioactivity levels of the waste at the end of 2010

Category	α (TBq)	Short-lived β/γ (TBq)	Long-lived β/γ (TBq)	Total radioactivity (TBq)
HLW	3,000,000	102,000,000	300,000	~105,000,000
ILW-LL	30,000	3,800,000	1,000,000	~4,800,000
LLW-LL	300	8,000	4,000	~12,000
LILW-SL (including T-LILW-SL)	800	19,000	7,000	~27,000
VLLW	2	2	1	5
UCTR	100*	-	-	100*

** Declared radioactivity level.*

This radioactivity evaluation shows that:

• **the HLW waste accounts for 96%** of the total activity levels of the radioactive waste generated up to 31 December 2010. This is the waste extracted from spent fuel (fission products and minor actinides generated in reactors). The main radionuclides accounting for over 98% of the radioactivity are:
- for the alpha radionuclides: curium-244, americium-241,
- for the short-lived beta-gamma radionuclides: caesium-137, strontium-90, promethium-147, caesium-134, europium-154,
- the long-lived beta-gamma radionuclides account for less than 1% of the radioactivity;

• **the ILW-LL waste accounts for 4%** of the total radioactivity. The activated waste from the reactors and the cladding waste from the nuclear fuel (CSD-C packages containing compacted hulls and end caps) accounts for over 90% of the total radioactivity of the ILW-LL waste. The main radionuclides contained in the activated waste are iron-55, cobalt-60, cadmium-109, tritium- and manganese-54 for the short-lived types, and nickel-63 and meta-stable silver-108 for the long-lived types. In the case of the cladding waste from fuel, the radionuclides that account for most of the radioactivity are iron-55, strontium-90, caesium-137, tritium- and cobalt-60 for the short-lived types and nickel-63 for the long-lived types;

• **the LLW-LL waste accounts for 0.01%** of the total radioactivity. The graphite waste contains mainly beta-gamma radionuclides, mostly tritium- and cobalt-60 for the short-lived types, and carbon-14, nickel-63 and small quantities of chlorine-36 for the long-lived types. The radium-bearing waste contains mainly radionuclides of natural origin emitting alpha radiation (radium, thorium, and uranium);

• **the LILW-SL waste accounts for 0.02%** of the total radioactivity. The lateral neutron protections from the EDF Creys-Malville reactor (Isère), together with the concrete packages containing drums of cemented ion exchange resins (IERs), stemming from treatment of the water from the storage ponds at the AREVA NC plant at La Hague (Manche district), are the most active waste families in the LILW-SL inventory. However, they only make up 6 and 8% of the total activity respectively due to their small volume as compared with other families in the LILW-SL category such as the packages of IERs stemming from treatment of the water from the coolant systems of the EDF reactors.

2.1

2.1.4

Breakdown of the waste by owner and by economic sector at the end of 2010

These breakdowns by owner and by economic sector do not take into account the waste without disposal solutions or the waste from the COMURHEX plant in Malvési (Aude district).

By owner

The *National Inventory* at the end of 2010 shows the breakdowns by owner resulting from data supplied by the producers AREVA, EDF and CEA on the one hand and, on the other hand, on the basis of evaluations made by Andra using data available for the waste stored at the Manche disposal facility, the LILW disposal facility and the VLLW disposal facility in the Aube.

Categories	2010 stocks (in cu. m)	CEA/civil share	AREVA share	EDF share	CEA/DAM share	Other shares
HLW	2,700	7.1%	8.8%	75.7%	8.5%	0%
ILW-LL	40,000	25.6%	16.2%	45.7%	12.1%	0.35%
LLW-LL	87,000	18.4%	12.1%	30.1%	18.4%	21.0%
LILW-SL	825,500	21.1%	21.4%	47.4%	5.5%	4.6%
VLLW	360,000	41.2%	23.4%	16.6%	14.4%	4.3%
V-LILW-SL	4,600*	0.1%	0%	0%	96.4%	3.6%

** Erratum january 2013.*

For the HLW and ILW-LL waste

EDF is owner of most of the waste stemming directly from the spent fuel whose processing is arranged for at Marcoule (Gard district) and at La Hague (Manche district), first by the CEA, and then by COGEMA as from 1976 (the date of its establishment).

Furthermore, AREVA is the owner in particular of the waste stemming from the fuel processed under contracts signed before 1977, which did not feature any clauses covering return of the waste (512 tonnes of spent fuel out of the total of 10,000 tonnes of spent fuel from outside France processed at the plant at La Hague (Manche district).

The legacy and current waste resulting from the activities carried out on the Marcoule (Gard district) site on behalf of the French Defence entities is owned by the CEA/DAM.

EDF, the civil CEA, CEA/DAM and AREVA are also owners of ILW-LL waste linked to operation of their own facilities.

Moreover, since the previous edition was published, the CEA has decided to withdraw the CEA spent fuel from the waste inventory for the Cigéo project. The fuel from Brennilis (Finistère district) is the only fuel whose disposal is planned.

For the LLW-LL waste

The graphite waste that is still in the reactors (stacks, reflectors in place, support areas) is not included in the stocks at the end of 2010.

Thus the breakdowns shown above only take into account the graphite waste already removed from the reactors (in particular sleeves constituting the structure of GCR fuel processed at La Hague (Manche district) and at Marcoule (Gard district)).

Concerning radium-bearing waste, some of the waste from the former plant at Le Bouchet (Essonne district) (9,600 cu. m) is classified as LLW-LL.

For the LILW-SL and VLLW waste

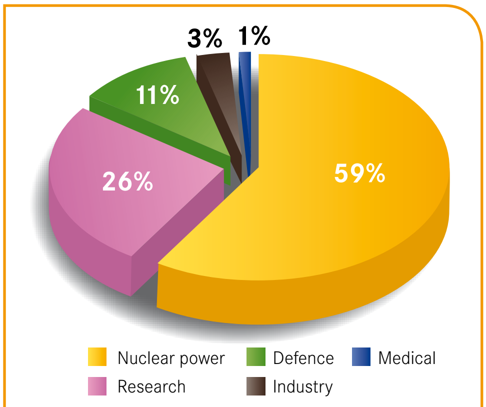
Most of the LILW-SL and VLLW waste stems from operation, maintenance and dismantling of facilities.

By economic sector at the end of 2010

The breakdown of radioactive waste by economic sector at the end of 2010 is shown in the figure below for each management solution.

The breakdown has been estimated by Andra on the basis of data including the breakdown by owner shown on the *previous page*.

Breakdown of the total volume of waste by economic sector



2.1

The radioactive waste allocated to the **"nuclear power"** economic sector corresponds to the waste generated by the activities linked to making fuel, the nuclear power plants, the spent fuel processing plants, and the waste treatment facilities and their maintenance.

Most of the waste in the HLW, ILW-LL and LILW-SL categories stems from this economic sector.

The waste allocated to the **"Defence"** economic sector brings together the waste stemming from the activities linked to nuclear deterrents and to the nuclear propulsion systems of certain ships and submarines, together with the corresponding research activities. It consists of waste from the CEA Military applications directorate (CEA/DAM) and the French national Defence entities (DGA, SSA, Army, Air Force and Navy, and Gendarmerie). In this sector, the waste in the HLW and ILW-LL categories is owned by CEA/DAM.

The **"research"** economic sector corresponds mainly to the waste generated by the CEA within the framework of its civil research activities, and to a lesser extent to the waste generated within the framework of research activities carried out on sites other than those of the CEA.
Amongst these sites, we can mention as examples the European nuclear research site at Prevessin (CERN) (Ain district), the Institut Laue-Langevin in Grenoble (ILL) (Isère district) or the Large heavy ion accelerator - Calvados (GANIL). The radium-bearing waste generated during the work to clean up the former uranium ore treatment plant at Le Bouchet (Essonne district) operated by the CEA between 1946 and 1970 has been conventionally allocated to this economic sector.
As set out above, the waste from the Defence research activities is allocated to the Defence economic sector.

The waste generated by industrial companies using naturally-occurring radioactive materials, and especially RHODIA in the field of extraction of rare earth elements, is included in the **"industry other than nuclear power"** economic sector. The other waste included in this economic sector comes from numerous other small industries *(see special report 3)*.
The lightning conductors made between 1932 and 1986 and progressively removed and collected by Andra, also form part of this economic sector *(see special report 2)*. It is to be noted that the percentage of ILW-LL waste allocated to the "industry other than nuclear power" economic sector corresponds to the "source blocks" containing spent sealed sources collected from small waste producers in the 1970s and 1980s. This waste is stored at the CEA establishment in Cadarache (Bouches-du-Rhône district).

Lastly, the **"medical"** economic sector brings together the waste stemming from therapeutic and medical diagnosis activities, together with the waste generated by research in the medical field, most of which has already been collected and disposed of by Andra.

2.2
Radioactive waste: forecasts for the period 2011 - 2030

As set out in the introduction to this chapter, the only types of waste evaluated are those corresponding to operation, waste recovery and conditioning, and dismantling of facilities licensed as at the end of 2010.

To estimate future levels of waste production, we have to make assumptions and define production scenarios. These assumptions and scenarios take into account any changes forecast by the industrial entities concerned.

We have thus assumed that nuclear power production will continue, with treatment of all spent fuel, apart from the fuel from the prototype heavy water reactor at Brennilis (Finistère district).

To evaluate the forecasts for end-2020 and end-2030 for the present edition of the *National Inventory*, the assumptions adopted as to the constitution, operation, cleanup and dismantling of the nuclear power plants and the fuel cycle plants, are as follows:

- **there are 59 licensed nuclear power reactors** (the 58 existing reactors and the EPR reactor being built on the Flamanville site (Manche district) whose planned commissioning date is 2016);
- **the service life of the reactors** is the same for all the reactors, and it is set at 50 years;
- **electricity production from nuclear power plants** is almost 430 TWh/year, to which is added 13 TWh/year as from 2016, when the EPR reactor is due to come into operation *(see chart below)*; this level of production will continue until the first of the of 900 megawatt reactors is decommissioned, and then it will fall as the more recent reactors are decommissioned;
- deployment of **fuel with high burnup** is not adopted;
- **the plutonium** extracted during treatment of spent fuel is recycled in the form of MOX assemblies at a rate of 120 HMt[4]/year; this tonnage is divided up between the 22,900-megawatt, reactors licensed to load this type of fuel;
- **the uranium extracted during treatment of spent fuel** is recycled, in the form of ERU (enriched recycled uranium) assemblies at a rate of 74 HMt/year; this tonnage is divided up between the four reactors at Cruas (Ardèche district) licensed to load this type of fuel;
- **the COMURHEX plant in Malvési (Aude district) will continue** its activities using the current process and with its current capacity.

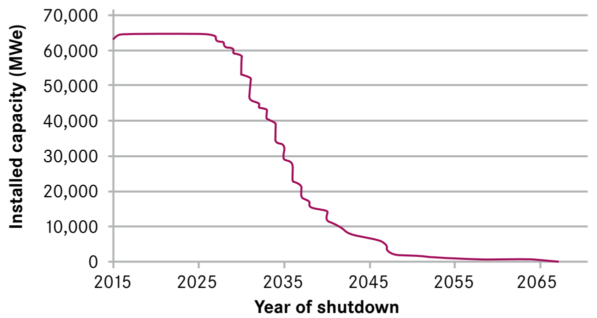
The waste generated by the ITER facility is not taken into account in the 2012 edition of the *National Inventory*, because construction of the facility was not licensed as at the end of 2010.

The operating assumptions set out above lead to unloading 1,200 HMt of PWR fuel per year on average (including 120 HMt of MOX fuel).

Dismantling work on the PWR reactors currently operating will not begin before 2030. In the same way, dismantling of fuel processing plants UP2-800 and UP3 at La Hague (Manche district) is envisaged by AREVA after 2030.

At the end of 2030, dismantling work will be under way on some of the present facilities on the various civil CEA and CEA/DAM (Military applications directorate) research sites.

Changes in the installed capacity depending on the dates of definitive shutdown of the reactors with a service life of 50 years



4 *HMt (tonne of heavy metal): tonne of uranium or plutonium contained in the fuel before irradiation.*

2.2.1
Forecast quantities of stocks in 2020 and 2030, taking all the economic sectors together

These forecasts have changed as compared with those made in 2007 and published in the 2009 edition of the *National Inventory*.

Category	Forecasts made in 2007	Forecasts made in 2010
	For 2020	For 2020
HLW	3,700	4,000
ILW-LL	47,000	45,000
LLW-LL	115,000	89,000
LILW-SL (including T-LILW-SL)	1,000,000	1,000,000
VLLW	630,000	762,000
Grand total	**~1,800,000**	**~1,900,000**

Category	Forecasts made in 2007	Forecasts made in 2010
	For 2030	For 2030
HLW	5,100	5,300
ILW-LL	51,000	49,000
LLW-LL	152,000	133,000
LILW-SL (including T-LILW-SL)	1,200,000	1,200,000
VLLW	870,000	1,300,000
Grand total	**~2,300,000**	**~2,700,000**

Concerning the waste from the COMURHEX plant in Malvési (Aude district), for which long-term management methods are currently being defined *(see page 25)*, the forecasts are as follows:

Category	Forecasts made in 2010	
	For 2020	For 2030
UCTR	635,000	688,000

2.2

The main factors accounting for the changes are as follows:

- **an increase in the annual processing flows** of spent fuel at the La Hague plant (Manche district) (1,000 HMt instead of 850), which translates into an increase in the volumes of HLW and ILW-LL waste;
- **the necessity of taking into account a longer service life for the nuclear facilities** (50 years instead of 40 years in 2007), which translates mainly into an increase in HLW, ILW-LL and LILW-SL waste;
- **enhanced identification of the waste** that will be generated during dismantling and by the operations to recover legacy waste, together with optimisation of the sorting.

The main effects of these changes are transfers of waste from the ILW-LL category to the LLW-LL or LILW-SL categories, and from the LILW-SL category to VLLW;

- **the shift of the schedule for dismantling the gas-cooled graphite-moderated reactors, which** puts back the date of production of the corresponding LLW-LL waste (graphite waste);
- **an increase in the volume of the VLLW waste** to be generated during clean-up of the civil engineering structures of the facilities to be dismantled, due to implementation of the new ASN guidelines concerning acceptable complete clean-up methodologies for INBs in France and to redirection of waste from the LILW-SL category to the VLLW management solutions.

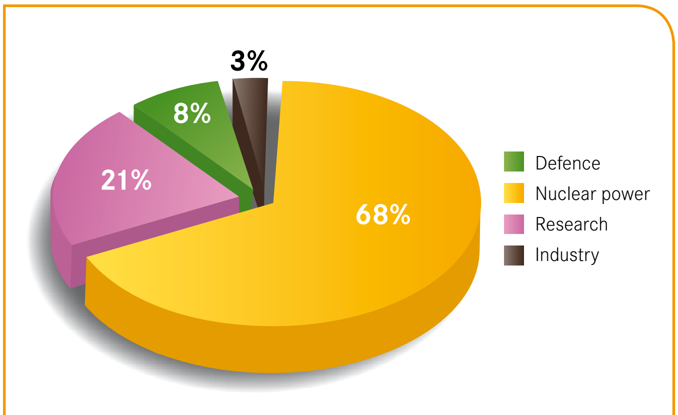
2.2.2
Stocks of waste by economic sector by 2030

The breakdown of the radioactive waste by economic sector (other than waste without disposal solutions and waste generated by the COMURHEX plant in Malvési - Aude district) as estimated by Andra at the end of 2030 is shown in the chart below.

Concerning the waste for all the management solutions, we can note the growing share of the nuclear power economic sector, especially for the HLW, LLW-LL and VLLW waste.

The dismantling operations (of first-generation GCR reactors, SuperPhénix reactor, and front-end facilities in the cycle) are the main factors behind the considerable increase for the LLW-LL and VLLW management solutions *(see chapter 3)*.

Breakdown of the volumes of waste at the end of 2030 by economic sector – the waste from the medical sector accounts for about 0.3% of the total volume.



2.2.3
Waste from dismantling over the period from 2010 to 2030

As the nuclear industry is a relatively recent industry (dating back to the early 1960s), the main clean-up and dismantling work on nuclear fuel cycle facilities is yet to come, and will take place mostly after 2020.

There are two types of waste that stem from the dismantling operations: radioactive waste, and conventional waste. This 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.

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 for example);
- tools and protective clothing (gloves, vinyl overalls, etc.);
- solutions used for rinsing equipments.

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 generated based on feedback from past dismantling operations.

This feedback is gradually built up in databases which are spent 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 made there.

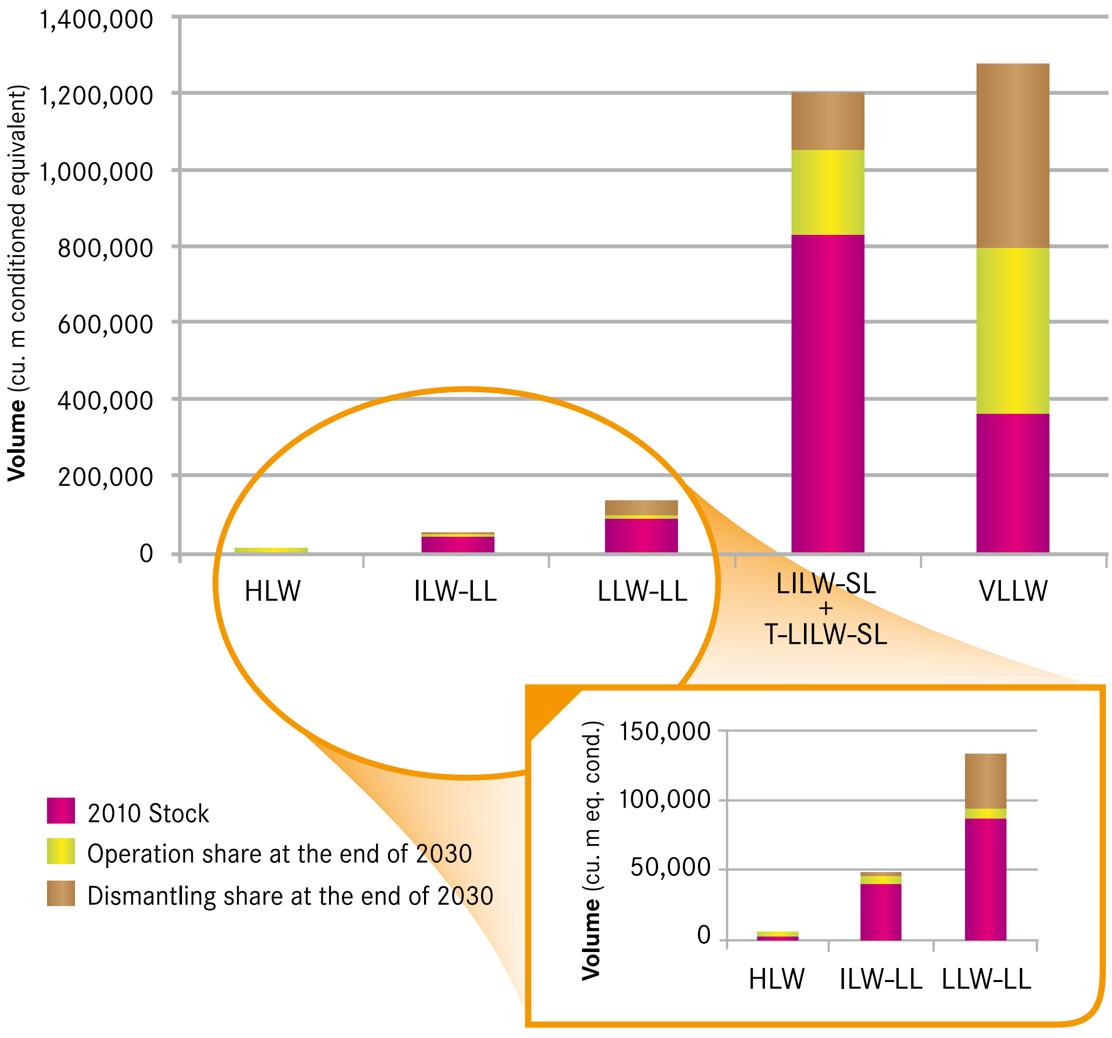
The evaluations take into account all the waste resulting from operation, including, for example, the volumes of effluent generated by decontamination. Depending on the characteristics of the waste, specific management scenarios are used to assess the quantities of conditioned waste and appropriate long-term management solutions.

These scenarios are based on knowledge of processing and conditioning facilities. They may vary from one producer to another, as each producer has its own strategy for dismantling its facilities.

2.2

The graph below shows the forecast quantities of waste generated at the end of 2030 for the various categories, setting apart the quantities of waste from dismantling. Most of the radioactive waste generated by dismantling operations is in the VLLW category, and to a lesser extent in the LILW-SL category. In some specific cases, and depending on the type of facility concerned, there may also be waste in the ILW-LL category. Dismantling of first-generation gas-cooled graphite-moderated reactors produces LLW-LL waste.

Forecasts of the quantities of waste at the end of 2030 and share of dismantling



2.3
Stocks of radioactive materials as at the end of 2010 and forecasts for the period 2011 - 2030

A radioactive material is defined in article L. 542-1-1 of the Environment Code as amended by the act of 28 June 2006, as "a radioactive substance for which a subsequent use is planned or envisaged, where applicable after processing" *(see chapter 1)*.

The following radioactive materials are presented in this chapter:

- **natural uranium from mining activities**
- **enriched uranium**
- **recycled uranium from spent fuel** after treatment (URT)
- **depleted uranium**
- **thorium**
- **suspended particulate matter** (a by-product of rare earth elements treatment)
- **fuel in use** at nuclear power plants and in research reactors
- **spent fuel** awaiting treatment
- **plutonium** obtained from spent fuel after treatment

Most of these materials are generated by the nuclear fuel cycle. In July 2010, the HCTISN (National committee for transparency and information on nuclear safety) published a report that provides a detailed overview of the issues linked to the fuel cycle concerning recycling of radioactive materials *(see box opposite)*.

2.3

Extract from the "Detailed analysis of the fuel cycle" made by the HCTISN [III]

In 2010, the National committee for transparency and information on nuclear safety made a detailed analysis of the flows of materials and waste generated at the various stages of the fuel cycle and the stocks of (valuable) "materials" held by the players in the nuclear field.

The overview arising from that analysis shows us that:

• each year, it takes something like 8,000 tonnes of natural uranium to make the quantity of fuel necessary to operate the French nuclear power plants, which consume about 1,200 tonnes of nuclear fuel;

• nuclear fuel is made mainly from enriched natural uranium; nonetheless, in France, recycling of the materials obtained by processing spent fuel (uranium and above all plutonium) leads to savings of natural uranium that are estimated at 12%;

• the savings of natural uranium are likely to rise as from 2010 (from 12% to 17%) thanks to increases in:

- the number of reactors using fuel made from depleted uranium and plutonium (from 20 to 22 reactors),
- the number of reactors using fuel made from recycled uranium (from 2 to 4 reactors);

• each year, something like 7,300 tonnes of depleted uranium is generated, to supply the French reactors:

- a small proportion (about 100 tonnes per year) is reused to make fuel containing plutonium,
- another part can be spent to make enriched uranium, by re-enrichment in current or future plants,
- most of it is currently stored with a view to reuse, which is envisaged in fourth-generation reactors;

• the French stock of depleted uranium can be evaluated at 450,000 tonnes in 2040; if the 4th generation reactors are indeed put into operation at that date, the stock would then represent, on the basis of the estimations made by the CEA and quoted in the PNGMDR, an abundant future resource for nuclear energy production;

• after use, the fuel made from recycled materials (which represents about 140 tonnes per year, and is likely to rise to 200 tonnes per year as from 2010) is currently stored, as these materials are only recycled once; they constitute a reserve of raw materials, and especially plutonium, for use when starting up the 4th generation reactors.

This analysis leads the National committee to note that some of the materials generated during the fuel cycle are indeed not currently recovered. They are stored with that possibility in mind. However, this is a credible prospect thanks to the 4th generation reactors that could be put into operation as from 2040 (if the technical, economic and political conditions remain favourable).

Moreover, taking into account the recycling prospects set out above, and under the terms of the French act of 28 June 2006 on long-term management of radioactive materials and waste, recycled uranium and depleted uranium are now classified as recoverable radioactive materials. Nonetheless, we must remember that classification as a material or waste is not definitive.

This evaluation is made on the basis of changes in technologies and of recycling prospects: new technologies may open up avenues concerning new possibilities of recycling, or on the contrary, a change in the industrial, political, technical and/or economic context may bring into question reuse that had been envisaged up to that point.

[III] *HCTISN Report published in July 2010: Opinion as to the transparency of management of the nuclear materials and waste generated at the various stages of the fuel cycle.*

The quantities of radioactive materials at the end of 2010, together with the sites on which they are stored, are shown below[5]. The stock varies depending on the levels of nuclear power production.

Natural uranium from mining activities

Natural uranium from mining activities is processed and converted into a solid uranium concentrate, and then conditioned. Depending on the treatment system spent, the concentrates can take the form of uranates, known as *yellowcake* or uranium oxide (U_3O_8). At 31 December 2010, about 16,000 tonnes of natural uranium were stored on the AREVA sites in Malvési (Aude district) and Pierrelatte (Drôme district), together with a small amount at the CEA. Natural uranium is then transformed into enriched uranium to make fuel.

Enriched uranium

Enrichment consists in increasing the levels of uranium 235 (an energy-producing isotope whose content of 0.8% in natural uranium is too low) in order to obtain a material that can be spent as fuel in the light water nuclear power plants.

The enrichment process implemented at the EURODIF Georges Besse I plant (Drôme district) is that of gaseous diffusion.

2.3

All the French mines are now closed, and natural uranium is imported from other countries.

Uranium, in the form of uranium hexafluoride gas (UF_6), travels through diffusers that separate the uranium-235 from the uranium-238, using the difference in their masses. Two flows are thus created: one enriched, and the other depleted, in isotope-235.

The enriched uranium spent for electricity production contains about 4% of uranium 235.

At 31 December 2010, just under 3,000 tonnes of enriched uranium were stored on the AREVA sites in Pierrelatte (Drôme district), Romans (Drôme district), Marcoule (Gard district), and La Hague (Manche district), on the CEA sites, and also on the EDF sites in the form of new UOX assemblies.

Depleted uranium (Udep)

Enrichment provides uranium enriched in uranium-235 on the one hand, and depleted uranium on the other hand. Uranium depleted in uranium-235 (an isotope present at a level of about 0.3%) is transformed into a solid, stable, incombustible, insoluble and non-corrosive substance: uranium oxide (U_3O_8), which takes the form of a black powder.

At 31 December 2010, about 272,000 tonnes of depleted uranium (Udep) were stored in France, with just over 165,000 tonnes on the AREVA site at Le Tricastin (Drôme district), about 100,000 tonnes on the AREVA site in Bessines-sur-Gartempe (Haute Vienne district) and 176 tonnes on the CEA sites; the remaining corresponds mainly to semi-finished products linked to making MOX fuel (a fuel made up of a mixture of uranium and plutonium) and to the stocks stored on the EDF sites, in the form of MOX assemblies and new fuel assemblies for fast breeder reactors.

Depleted uranium has been used regularly for several years as a support matrix for MOX fuel, which is made in France in the Melox plant located in Marcoule (Gard district). This flow accounts for about a hundred tonnes per year.

Furthermore, the stock of depleted uranium can be evaluated at 450,000 tonnes as at the end of 2040. This stock represents an abundant future resource for production of nuclear power. In a few years' time, developments in the enrichment techniques, with centrifugation, should enable re-enrichment of depleted uranium, under suitable economic conditions.

5 *By convention, new fuel is listed in the form of quantities of uranium and plutonium.*

These stocks of depleted uranium could be recovered for use in the 4th generation fast breeder reactors, whose deployment is expected after 2040. It is currently thought that a number of 4th generation reactors providing power levels equivalent to the current plants (i.e. 60 GWe) would consume about 100 tonnes of depleted uranium per year, once the reactors are put in service. Thus the stock of depleted uranium available when these reactors come into service would constitute a resource enabling the reactors to operate for several hundred years.

Uranium recycled from spent fuel after treatment (URT)

Uranium extracted from spent fuel (URT) in the treatment plants makes up about 95% of the mass of spent fuel and still contains a significant amount of isotope-235. The residual enrichment in uranium-235 is about 0.7% to 0.8% for PWR fuel with burnup levels of 45 to 55 GWd/t. For reuse in light water reactors such as those currently operated by EDF, further enrichment is necessary.

The URT is stored either in the form of UF_6, or in the form of U_3O_8, depending on the management method adopted (further enrichment to make fuel or disposal).

The French URT is owned mainly by the electricity utility EDF, and some is also owned by AREVA and the CEA.

At 31 December 2010, 24,000 tonnes of URT were stored on the sites of Le Tricastin (Drôme district), La Hague (Manche district), Romans (Drôme district) and Cruas (Ardèche district).

URT is partly recycled by EDF (in the four reactors at the plant in Cruas - Ardèche district) after further enrichment with uranium-235.

The quantity of URT recycled depends heavily on the market for natural uranium, with which URT is in competition.

Moreover, at 31 December 2010, 2,670 tonnes of URT from other countries were stored in France. This URT is owned by AREVA's customers in other countries, whose strategy is that of recycling to make fuel.

Thorium

Thorium takes the form of thorium hydroxide or thorium nitrate. About 9,400 tonnes are stored in France.

Within the framework of its treatment activities involving rare earth elements ores, Rhodia generated:

- between 1970 and 1987, a compound stemming from treatment using the monazite chloride method: crude thorium hydroxide (ThH), which could perhaps be recovered *(see box on page 48)*;
- up to 1994, thorium nitrate, generated by treatment using the monazite nitrate method.

At 31 December 2010, about 7,100 tonnes of thorium were stored in the form of nitrate and hydroxides on the site of the plant in La Rochelle (Charente-Maritime district).

There were also just under 2,300 tonnes of thorium stored on the CEA site at Cadarache (Bouches-du-Rhône district).

Lastly, a few tonnes of thorium owned by AREVA are stored on the sites at Bessines (Haute-Vienne district) and Le Tricastin (Drôme district).

Suspended particulate matter (SPM)

The suspended particulate matter (SPM) stemming from the process of neutralisation of the chemical effluents generated at the Rhodia plant contains an average level of 25% of rare earth elements oxides that are recoverable by-products *(see box on page 48)*.

At 31 December 2010, 23,500 tonnes of SPM, a by-product from treatment of rare earth elements, were stored on the site of the plant at La Rochelle (Charente-Maritime district).

Recycling of suspended particulate matter and crude thorium hydroxide

Recycling of these materials is being studied, especially by AREVA and RHODIA. It concerns their rare earth elements, thorium and uranium contents.

Rare earth elements are spent in numerous consumer products such as flat screens, certain batteries, optical fibres or lenses, etc. About 10,000 tonnes of rare earth elements oxides can be recovered by processing suspended particulate matter (SPM) and crude thorium hydroxide (ThH).

Thorium could be recoverable in nuclear applications. In a situation of shortage concerning uranium resources, the thorium cycle could be used in 4th generation reactors.

Thorium is also recoverable in non-nuclear industrial sectors:

- in the medical field for cancer treatment using alpha radio-immunotherapy, lead-212 generated during disintegration of thorium-232 and -228 is grafted on an antibody that specifically recognises certain cancer cells. The alpha radiation from lead-212 then destroys those cells;
- thorium oxide can be used in glass lenses with high refraction indices, for example.

Lastly, like that for thorium, future worldwide demand for uranium can doubtless not be met by mining production and the use of recycled and depleted uranium. Studies are thus being carried out to extract uranium from crude thorium hydroxide.

2.3

Fuel in use and spent fuel

At all times, there are stocks of fuel in use or spent fuel.

These stocks are considered by their owners as recoverable radioactive materials because of the uranium and plutonium that they contain. A distinction is usually made between:

- fuel containing uranium oxide, which is the most widespread fuel. EDF mainly uses fuel with enriched natural uranium (UOX), and, in smaller quantities, fuel with re-enriched uranium from treatment (ERU);
- mixed uranium oxide - plutonium oxide fuel (MOX), that EDF is licensed to use in some of its power plants;
- fuel from the Phénix and SuperPhénix fast breeder reactors, which is no longer used (the plants have been decommissioned);
- fuel for the civil CEA, which is used in specific reactors for research purposes. There is a wider range here as to form and physico-chemical composition than for the EDF fuel. It also exists in much smaller quantities;
- fuel for the French national Defence entities, which is used either in reactors designed to make materials for the nuclear deterrent weapons, or in the reactors on board submarines and ships, together with their prototypes on land.

EDF's strategy consists in giving priority to processing of fuel with enriched natural uranium oxide. Treatment of ERU and MOX fuels will be carried out as from 2030.

After unloading, the EDF fuels are stored in ponds while they decay, initially in the power plants themselves, and then at the AREVA NC plant at La Hague (Manche district).

Fuel in use in nuclear power and research reactors

The following quantities of fuel were in use in the French nuclear power plants at 31 December 2010:

- about 4,500 HMt of UOX fuel in the 19 French PWR nuclear power plants;
- 156 HMt of ERU fuel in the four reactors of the nuclear power plant in Cruas (Ardèche district);
- about 300 HMt of MOX fuel in the following nuclear power plants: Blayais (Gironde district), Chinon B (Indre-et-Loire district), Dampierre (Loiret district), Gravelines (Nord district), Saint-Laurent-des-Eaux B (Loir-et-Cher district) and Le Tricastin (Drôme district).

Spent fuel awaiting processing

The following quantities of fuel were stored while awaiting processing at the end of 2010:

- spent UOX fuel: 3,626 HMt on the sites of the 19 French PWR nuclear power plants, together with about 8,380 HMt on the site at La Hague (Manche district);
- spent ERU fuel: 68 HMt on the site of the nuclear power plant in Cruas (Ardèche district), together with about 250 HMt on the site at La Hague (Manche district);
- spent MOX fuel: 387 HMt on the sites of the following nuclear power plants: (Gironde district), Chinon B (Indre-et-Loire district), Dampierre (Loiret district), Gravelines (Nord district), Saint-Laurent-des-Eaux B (Loir-et-Cher district) and Le Tricastin (Drôme district), together with 900 HMt on the site at La Hague (Manche district);
- spent ENR fuel: 104 HMt on the site at Creys-Malville (Isère district);
- spent fuel from civil research reactors (other than metal fuels): 53 HMt of fuel including 43 HMt of spent FNR fuel from the Phénix reactor on the CEA sites, together with 2 HMt of fuel on the site at La Hague (Manche district);
- spent metal fuel from the experimental CEA reactors and GCR reactors: 15 HMt on the CEA sites;
- spent fuel from naval propulsion: about 146 tonnes.

Plutonium extracted from spent fuel by processing

The plutonium contained in the spent fuel assemblies is extracted from them during their processing. Spent uranium fuel of the light water type currently contains about 1% of plutonium (by weight). That plutonium can be used to produce energy.

After it has been dissolved, extracted and separated from the other materials contained in spent fuel, the plutonium is purified and conditioned in the stable form of plutonium oxide (PuO_2) powder in units R4 and T4 of the plant at La Hague (Manche district).

Plutonium is currently used to make MOX fuel, which includes 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. This type of fuel accounts for just under 10% of nuclear power production in the country.

The plutonium extracted from spent fuel is owned by AREVA's customers, i.e. electricity producers in France or in other countries. It is usually forwarded to the customers outside France in the form of MOX fuel for use in reactors in other countries.

At 31 December 2010, about 80 tonnes of plutonium were stored in France, including:

- 60 tonnes of plutonium stored at the AREVA NC plant at La Hague (Manche district);
- 8 tonnes of plutonium in use to make MOX fuel (in the form of PuO_2, of mixed oxide $(U,Pu)O_2$ or finished MOX assemblies);
- 10 tonnes of plutonium in non-irradiated MOX or ENR assemblies stored outside the manufacturing plants, i.e. mainly on the sites housing EDF reactors;
- about 2 tonnes of plutonium stored in various CEA facilities.

Out of these 80 tonnes of plutonium, 56 tonnes are owned by French entities. Of those 56 tonnes, the EDF stock of separated plutonium at La Hague (Manche district) stands at about 27 tonnes, enough to make MOX fuel for almost three years.

The stock of plutonium for military activities is a defence secret.

The radioactive materials as at the end of 2010, together with the forecasts concerning production of materials at the end of 2020 and the end of 2030 are shown in the *table below*. The forecasts for 2020 and 2030 are approximate, as they depend on the management choices made by each industrial concern in the light of the economic conditions at the time.

For the materials linked to the nuclear fuel cycle, the production scenarios for 2020 and 2030 are the same as those used for the waste *(see page 39)*.

Radioactive materials at the ends of 2010, 2020 and 2030

MATERIAL	2010	2020	2030
Mixed uranium-plutonium fuel (MOX) in use in nuclear power plants *(HMt)*	299	490	380
Spent mixed uranium-plutonium fuel (MOX) awaiting treatment *(HMt)*	1,287	2,400	3,800
Spent fuel from the Superphénix fast breeder reactor awaiting treatment *(HMt)*	104	104	104
UOX fuel in use in nuclear power plants *(HMt)*	4,477	4,340	3,650
Spent UOX fuel awaiting treatment *(HMt)*	12,006	11,450	12,400
ERU fuel in use in nuclear power plants *(HMt)*	156	290	290
Spent ERU fuel awaiting treatment *(HMt)*	318	1,050	1,750
Spent fuel from civil research reactors (including Phénix) awaiting treatment *(HMt)*	53	14	9
Spent metal fuel awaiting treatment *(HMt)*	15	15	15
Suspended particular matter (by-products of treatment rare earth elements ores - *tonnes*)	23,454	0	0
Fuels from the French national Defence entities *(tonnes)*	146	218	284
Plutonium from processed spent fuels *(HMt)*	80	55	53
Thorium *(tonnes)*	9,407	9,334	9,224
Depleted uranium *(HMt)*	271,481	345,275	454,275
Enriched uranium *(HMt)*	2,954	2,344	2,764
Uranium from processed spent fuels *(URT - HMt)*	24,100	40,020	40,020
Natural uranium from mining activities *(HMt)*	15,913	25,013	28,013

2.3

2.4 Outlook beyond 2030

The purpose of this paragraph is to provide a prospective overview of the waste and materials that would be generated by all the facilities licensed at the end of 2010 until the end of their service life, including dismantling, on the basis of two deliberately contrasting energy scenarios, without any presumptions as to the French energy policy adopted.

Scenario 1:

In this scenario, we assume **electricity will continue to be produced in nuclear power plants.**

Although such continuation presupposes replacement of some reactors, the waste generated by the future reactors is not evaluated, because they have not yet been licensed. Thus the inventory only covers the waste generated by the reactors licensed at the end of 2010.

On the other hand, all the spent fuel unloaded from the reactors is processed to recover the materials that can be extracted (recycled uranium, plutonium) for use in the current or future facilities.

It is on the basis of this scenario that the waste levels by 2020 and 2030 as shown above were evaluated.

Scenario 2:

This scenario translates **phasing out nuclear power on completion of the existing reactors' service life:** in this scenario, no new replacement plants are built.

The spent fuel is then no longer processed, because there is no point in recovering plutonium.

The main difference between the two scenarios considered is in the assumption concerning the service life of the PWR reactors: 50 years for the scenario of ongoing nuclear power production, and 40 years for the scenario without renewal of the facilities.

Operation of a PWR reactor for 50 years is a conventional assumption reflecting EDF's strategic orientations concerning extension of reactor service life beyond 40 years. It does not make any presumptions as to the decisions made by the ASN, the only authority empowered to issue licenses to extend service life, on a case-by-case basis, after the ten-year inspections.

For these two scenarios, we set out to determine the possible volumes of waste and quantities of materials generated by all the nuclear facilities until the end of their operation life.

The estimations thus made are simply orders of magnitude, and neither scenario is intended to set out an industrial reality.

When making these estimations, the operating waste is set apart from the dismantling waste. Indeed, the overall volume of the latter does not depend on the facilities' service life; the production flows are the only aspects that could vary depending on the assumptions as to operation life, and also on the schedules for the dismantling operations.

The operating waste is in turn subdivided into two sections:

- waste resulting directly from nuclear production of electricity, i.e. the waste generated by the nuclear power reactors and the plants at the front and back ends of the cycle;
- waste generated by the other facilities (research reactors or laboratories, facilities related to the nuclear deterrent weapons, etc.).

Only the former depend on the energy scenario envisaged.

The two scenarios adopted within the framework of this overview are based on shared assumptions:

- there are 59 licensed nuclear power reactors: the 58 existing reactors and the EPR reactor being built on the Flamanville site (Manche district) that is scheduled to be put into service in 2016.

- electricity production from nuclear power plants is close to 430 TWh/year, to which we can add 13 TWh/year as from 2016, when the EPR reactor is due to come into operation; this level of production will continue until the first of the of 900 megawatt reactors is decommissioned, and then it will fall as the more recent reactors are decommissioned;
- deployment of fuel with high burnup is not adopted;
- the principles of fuel management (types of assemblies, number per re-load sequence, enrichment, rate of combustion and lengths of the campaigns) are identical in both scenarios;
- the plutonium extracted during processing of spent fuel is recycled, in the form of MOX assemblies at a rate of 120 HMt/year; this tonnage is divided up between the twenty-two 900-MWe reactors licensed to load this type of fuel;
- the uranium recovered during processing of spent fuel is recycled, in the form of ERU assemblies at a rate of 74 HMt/year; this tonnage is divided up between the four reactors at Cruas (Ardèche district) licensed to load this type of fuel;
- the ILW-LL waste from ITER has been taken into account in the evaluations, to remain coherent with the waste inventory to be included in the Cigéo project, even though the ITER facility was not licensed at the end of 2010;
- the waste linked to uranium conversion in the COMURHEX plant in Malvési (Aude district) after 2030 is not taken into account in the estimations.

2.4

The operating assumptions set out above lead to unloading an average of 1,200 HMt of PWR fuel per year (including 120 HMt of MOX type fuel).

The results of the evaluations made are shown below on the basis of these two scenarios.

2.4.1 Scenario 1: Ongoing production of nuclear power

This scenario presupposes treatment of all the spent fuel from nuclear power, except that from the Brennilis reactor, and hence continuation of the treatment activities, on a base of about one thousand HMt of fuel per year.

It does not involve any presumptions as to the numbers or types of reactors built to replace the existing reactors; the waste and materials generated by the future reactors are not included in the present inventory, as they were not licensed at 31 December 2010. In fact, it postulates the existence, after replacement of the facilities, of reactors able to consume the plutonium recovered but not consumed in the existing facilities.

The assumption of a uniform service life of 50 years for all 59 reactors would lead to shutting them down definitively between 2027 and 2066.

The cumulative quantity of PWR fuel unloaded would then be close to 64,000 HMt (58,000 HMt of UOX, 4,000 HMt of MOX and 2,150 HMt of ERU).

The treatment flows adopted (1,000 HMt of UOX per year) balance out the plutonium recycling flows while the 22 existing MOX-enabled units remain in operation.

Thus the plutonium isolated during treatment is fully re-used in the MOX assemblies loaded in the existing reactors. Taking into account the forecast schedule for definitive shutdown (after 50 years of operation) of these 22 MOX-enabled reactors and the quantities of plutonium constituting the usable stock and the semi-finished products, the corresponding simulations show that separation of quantities of plutonium just sufficient to fuel these reactors until the end of their service life would be reached in about 2028 or 2029, i.e. after processing 34,000 HMt of UOX.

Beyond that date, the plutonium obtained from treatment would constitute a strategic reserve to fuel the new reactors to be built.

About 30,000 HMt of PWR fuel would then remain to be processed, together with the 180 HMt of ENR fuel from the SuperPhénix reactor.

The material will be separated progressively (as is currently the case) to meet the actual fuel requirements to feed the new reactors, which depends directly on their rate of deployment.

Studies on various deployment scenarios for future facilities are being carried out within the framework of research into the 4th generation reactors, in particular to enable us to establish a methodology for estimating the overall quantities of radioactive materials and waste generated by a given number of nuclear power facilities *(see box below)*.

If these operations are spread over about forty years (2030-2070), the average annual plutonium production rate would be about 13 tonnes.

Extract from the CNE evaluation of the studies for the scenarios [IV]

In a study carried out jointly by the CEA, EDF and Areva, three versions of nuclear power plants generating 430 TWhe/year were studied in detail:

- facilities featuring PWR plants with an annual production of 10 tonnes of plutonium, 1 tonne of minor actinides and 7,000 tonnes of depleted uranium resulting from enrichment of uranium-238. Operation of these facilities would lead to accumulation of about 1,900 tonnes of plutonium by 2150.
- facilities featuring PWR plants that use MOX (mono-recycling of plutonium), which would reduce the plutonium production levels. This would lead to accumulation of about 1,300 tonnes of plutonium by 2150.
- facilities featuring FBR plants (fast neutrons reactor) that would have an annual production of 2 tonnes of minor actinides and require 50 tonnes of depleted uranium. These facilities would use multiple recycling of plutonium and enable use of depleted uranium, in small quantities as compared with the existing stock of over 220,000 tonnes. It would enable the uranium-235 enrichment operation to be avoided. It would lead to stabilisation of the stocks of plutonium at about 900 tonnes by 2150.

The first two scenarios involve reactors whose technology is mature. However, they entail ongoing operation of the mining industry and the operations to enrich uranium with uranium-235. If we pursue this strategy, the plutonium from spent fuel is a waste item that continues to accumulate. *In fine*, the glass used for disposal would contain plutonium.[6]

The third scenario involves a more innovative technology, but one that is based on feedback from ENR. It would no longer entail enrichment of uranium with uranium-235, as the stock of 900 tonnes of plutonium generated constitutes a continuously recyclable resource until the reactors are decommissioned, even if their operating period covers several centuries. That stock will then have to be managed as an item of waste.

A scenario that has not yet been presented is that of early abandonment of nuclear power, which would pose the question of management of all the nuclear materials, which would thus de facto become waste.[7]

6 *Editor's note: or the plutonium accumulated could be left in the spent MOX fuel, which would then be waste for geological disposal.*

7 *Editor's note: in the case of this scenario (non-renewal of the facilities) the extra waste has been evaluated at about 28,000 HMt of spent fuel.*

[IV] *CNE: Evaluation report No. 5 published in November 2011. Evaluation of the research and studies concerning management of radioactive materials and waste.*

Concerning the uranium generated by treatment, the residual quantity at the end of the service life will lie between 0 and 40,000 tonnes of URT, with the maximum value corresponding to the assumption as to stability of the current recycling level in the four reactors at Cruas (Ardèche district) until the end of their service life.

Full resorption of the material stock is possible from a technical standpoint: it presupposes manufacture of almost 5,000 HMt of ERU fuel, a quantity that could be consumed, subject to the corresponding administrative licenses, in some or all of the existing reactors, in a comparable way to the recycling currently implemented at Cruas (Ardèche district).

A statement of the waste generated by electricity production from nuclear power stations is shown in the table below.

Scenario involving ongoing electricity production using nuclear power: estimation of the waste in conditioned equivalent cu. m.

Category	Ongoing electricity production using nuclear power
HLW	10,000
ILW-LL	70,000
LLW-LL	165,000
LILW-SL	1,600,000
VLLW	2,000,000

2.4.2 Scenario 2: Non-renewal of the nuclear power production facilities

The scenario set out in the paragraph above is based on continuity of the processing operations for all the spent fuel from nuclear power, other than that from the Brennilis reactor (Finistère district). It thus postulates the existence of reactors able to recycle the materials separated and not reused in the current facilities.

Inversely, the main objective of the non-renewal scenario is that of avoiding production, through treatment of fuel, of materials that could not be recycled in the existing reactors. This constraint thus leads to an early halt in the treatment activities, a provision that is in sharp contrast with the long-term future of that activity in the scenario involving continued production using nuclear power.

The non-renewal scenario arbitrarily adopts a service life of 40 years for the 59 reactors, which would mean shutting them down definitively ten years earlier than in the scenario set out above (i.e. between 2017 and 2056).

The cumulative quantity of PWR fuel unloaded would hence be something like 52,000 HMt (48,000 HMt of UOX, 2,800 HMt of MOX and 1,400 HMt of ERU). As the semi-finished products and the usable stock are identical to those in the previous scenario, the corresponding simulations show that separation of quantities of plutonium just sufficient to fuel the 22 MOX-enabled reactors until the end of their service life would be reached in about 2018 or 2019, i.e. after treatment 24,000 HMt of UOX.

Cessation of all fuel treatment operations as from that date would mean transforming all the spent PWR fuel not processed at that date, and the future amounts (i.e. about 28,000 HMt), into waste for direct disposal.

2.4

Scenario involving non-renewal of the nuclear power production facilities: estimation of the waste in equivalent conditioned cu. m

Category		Non-renewal of electricity production using nuclear power
HLW	Spent UOX Fuel	~ 50,000 assemblies*
	Spent ENR Fuel	~ 1,000 assemblies*
	Spent MOX Fuel	~ 6,000 assemblies*
	Vitrified waste	3,500
ILW-LL		59,000
LLW-LL		165,000
LILW-SL		1,500,000
VLLW		1,900,000

* Spent fuel is not currently considered as waste, so it is not conditioned for disposal. As the average volume of a fuel assembly is about 0.2 cu. m, these assemblies represent a crude volume of about 12,000 cu. m. Andra checked the feasibility of deep disposal of spent fuel in 2005.

The concepts of the disposal conditioning used for the demonstration led to a disposal package volume of about 89,000 cu. m (about eight times more than the unconditioned volume).

In this scenario, all the plutonium recovered during UOX treatment operations is recycled in the form of MOX fuel (2,800 HMt).

Concerning the uranium from treatment, the residual quantity at the end of the reactors' service life will lie between 0 and 10,000 tonnes of URT, with the maximum value corresponding to the assumption as to stability of the current recycling level (in the four reactors at Cruas (Ardèche district) until the end of their service life).

Full resorption of the material stock is possible from a technical standpoint: it presupposes manufacture of about 1,250 HMt of ERU fuel, a quantity that could be consumed, subject to the corresponding administrative licenses, in some or all of the existing reactors, in a comparable way to the recycling currently implemented at Cruas (Ardèche district).

As a conclusion for the scenario involving non-renewal of the nuclear power reactors after a 40-year service life, it is possible to leave no plutonium or URT unused, subject to early shutdown of the treatment operations (the 2018-2019 horizon guarantees full reuse of the plutonium extracted) together with increased recycling levels for the uranium obtained from treatment.

On the other hand, this scenario leads to production of extra waste (28,000 HMt of spent fuel for disposal at Cigéo[8]).

A statement of the waste generated under this scenario is shown in the table opposite.

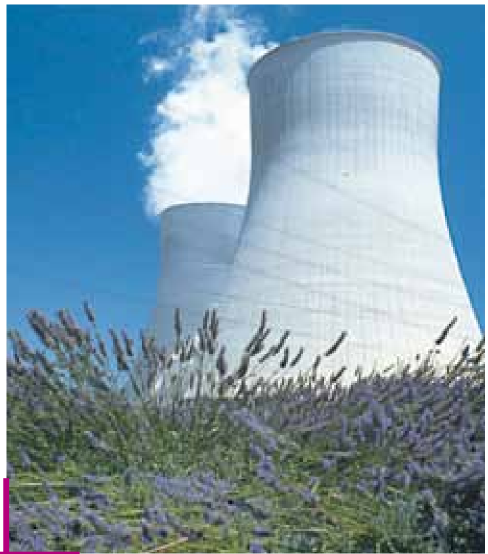
8 *Cigéo: Industrial Center for Geological Disposal.*

3

Inventory by economic sector

Inventory by economic sector

This chapter presents, for each of the economic sectors, the radioactive materials and waste listed at 31 December 2010 and estimated to the 2020 and 2030 horizon, based on a scenario that assumes the continuing use of nuclear power for the production of electricity, described in Chapter 2.



Cruas Nuclear Power Plant (Ardèche district)

As a reminder, the five economic sectors are defined as follows:

Nuclear power industry

which mainly includes nuclear power plants for electricity production, as well as facilities dedicated to the production and processing of nuclear fuels (extraction and treatment of uranium ore, chemical conversion of concentrated uranium, enrichment and production of fuel, processing of spent fuel and recycling *(see box, page 26)* ;

The Defence sector

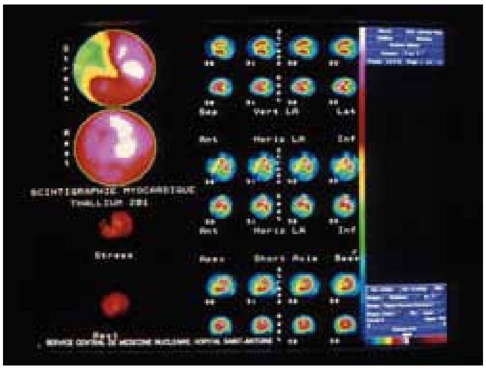
This mainly concerns activities relating to deterrents, including nuclear propulsion for certain ships and submarines, as well as for the associated research activities.

Submarine Le Redoutable

3.

Research

Industry – Smoke detector



Medical sector

The research sector

This includes civil nuclear research, medical research laboratories, particle physics, agronomy, chemistry, etc.

The industrial sector (excluding nuclear power)

This concern in particular extraction of rare earth elements, manufacture of sealed sources and also various applications such as weld inspections, sterilisation of medical equipment, sterilisation and conservation of food products, etc.

The medical sector

This includes therapeutic, diagnosis and research activities.

The presentation adopted for each economic sector is as follows:

- **description of the economic sector;**
- **statement of the waste produced** per management solution for the sector concerned at 31 December 2010; detailed status per site of the stocks listed and presented in the Geographical Inventory available separately;
- **production forecast statement** of waste per management solution in 2020 and 2030;
- **radioactive material statement** at 31 December 2010.

3.1 Nuclear power industry

This economic sector includes the manufacture of fuel, nuclear power plants, fuel recycling, waste treatment and the maintenance of installations.

3.1.1 Fuel manufacture

Conversion

After purification of the uranium contained in the mined ore, it has to be transformed into uranium hexafluoride, the only form that can be in a gaseous state at a temperature of 60°C: this is the conversion step. This gaseous state is essential for its circulation in the enrichment plants.

This transformation is in two steps:

- in the COMURHEX plant at Malvési (Aude district) where the *yellowcake* is converted into uranium tetrafluoride;
- then in the COMURHEX plant at Pierrelatte (Drôme district) where a fluoridation procedure changes the uranium tetrafluoride into uranium hexafluoride.

The chemical process used at the COMURHEX plant at Malvési (Aude district) generates solid residues and liquid effluents.

This waste, loaded with solid uranium bearing material is currently managed in a pond system.

3.1

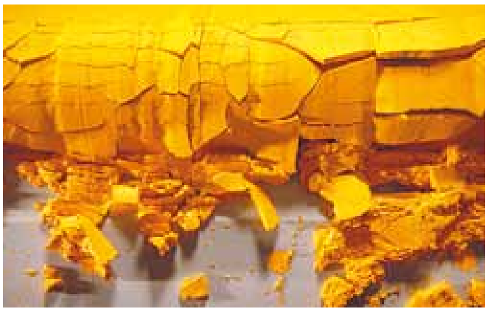
The solid residue is stored in open air settling ponds and the liquid effluent in evaporation ponds. These residues are not conditioned.

COMURHEX plans the commissioning of new installations in 2013 aimed at modernising the conversion plant.

The waste produced by the COMURHEX plant at Malvési (Aude district) is shown separately in the following statements. In fact, at the end of 2011, AREVA issued a study on the long-term management of this waste as part of the PNGMDR. This study is being investigated. Pending a decision on the long-term management of this waste, this family is presented separately in the figures for waste stocks existing at 31 December 2010 and in the forecasts.

Waste from the extraction and treatment of uranium ore

Uranium mining in France ended in 2001. The waste from ore treatment is permanently stored on the former mining sites *(see chapter 4)*.



Concentrated uranium yellowcake on a belt filter

Crystals of UF_4 (uranium tetrafluoride)

Crystals of UF_6 (uranium hexafluoride)

Uranium pellets (FBFC plant at Romans - Drôme)

Enrichment

Natural uranium is mainly composed of two isotopes: uranium-238 and uranium-235. The fissile uranium-235 is considerably less abundant in the natural state than uranium-238: it only represents 0.71 % of natural uranium.

Today, most reactors use uranium enriched to 3 to 5% with uranium-235 as fuel.

Enrichment therefore consists of increasing the proportion of uranium-235.

EURODIF's Georges Besse I plant (Drôme district) uses the gaseous-diffusion enrichment process. Gaseous uranium flows through the diffusers that separate the uranium-235 and uranium-238 by exploiting the difference in the atomic weight of these two isotopes. This creates two flows: one enriched with the 235 isotope and one depleted. The Georges Besse II plant (Drôme district), which uses the centrifuge process, is progressively taking over from this installation *(see box page 73)*.

The fuel conversion and enrichment facilities produce waste with low-level radioactivity or very low uranium contamination, disposed of at the LILW disposal facility (LILW-SL) and the VLLW disposal facility in the Aube district. They are generally packed in drums or cement containers.

Manufacture of the fuel rod assembly

The fuel manufactured for electricity production is essentially of two types: UOX (uranium oxide) and MOX (mixed uranium oxide and plutonium oxide).

UOX fuel (uranium oxide)

The enriched uranium hexafluoride is converted into uranium oxide powder, and then compacted into pellets to manufacture the 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 district). The waste produced by the plant is essentially very-low-level waste from the operation and maintenance of the installations.

MOX fuel (mixed uranium oxide and plutonium oxide)

AREVA's MELOX plant located at the Marcoule site (Gard district), has been manufacturing MOX fuel since 1995 using a process similar to that for UOX, but with a blend of uranium oxide and plutonium oxide powders.

The plutonium comes from treatment of spent fuel at the AREVA NC plant at La Hague (Manche district).

The waste produced by MELOX is LILW-SL and ILW-LL technological waste, parts of which are not irradiated and are contaminated by alpha-emitting radionuclides.

Carousel of plutonium cans at the AREVA Melox MOX fuel manufacturing plant at Marcoule

The AREVA Cadarache facility (Bouches-du-Rhône district), previously belonging to the CEA, also produced MOX until July 2003.

MOX fuel manufacturing plants

The production of MOX fuel at Cadarache has now been stopped. The initial pilot operations to dismantle the Cadarache plant started in 2007. The MELOX plant started operating in 1994. Its current capacity is 190 HMt of MOX fuel per year (heavy metal weight), intended for French and foreign "light water" units.

Visual inspection of the UOX fuel assemblies (AREVA)

3.1

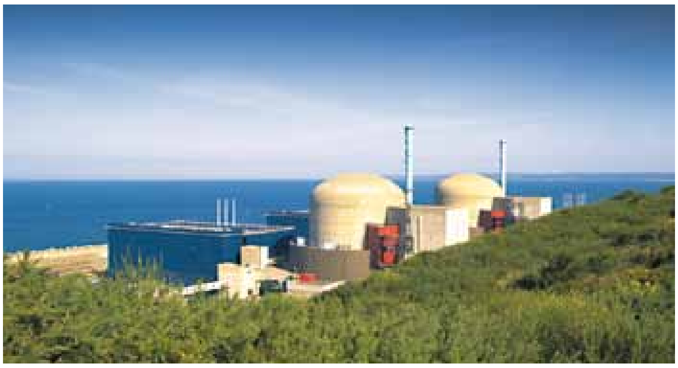
3.1.2
Nuclear power plants for electricity production

Reactors in operation

There are currently 58 French nuclear reactors operating on 19 different geographic sites *(see table on page 64)*.

In France, all the nuclear power plants in operation are light water units, that is 58 PWRs (Pressurised water reactors operating with enriched uranium) commissioned from 1977 to 2000 *(see table on page 64)*.

An additional nuclear power plant, a pressurised water reactor of the EPR type, will be completed at the end of 2016 (Flamanville - Manche district).



Flamanville Power Plant (Manche district)

Bugey Power Plant (Ain district)

Some figures on the waste produced by pressurised water reactors

- a PWR produces an average of 150 cu. m radioactive waste per year (excluding fuel), mostly LILW-SL and VLLW, with two-thirds LILW-SL and one-third VLLW.
- spent fuel treatment produced annually, for one reactor, approximately 2.5 cu. m of HLW waste and 3 cu. m of ILW-LL.
- dismantling: it is estimated that dismantling of a PWR produces on average 18,000 cu. m of radioactive waste and that the demolition of the buildings generates approximately 10 times more non-radioactive concrete rubble.

Operating reactors

Sites and dates (1st reactor coupled to network-last reactor)	Number of reactors operating-series	Net power output per reactor
Fessenheim - Haut-Rhin district - (04/1977 – 10/1977)	2 - REP	880 MWe*
Bugey - Ain district - (05/1978 – 07/1979)	4 - REP	910/880 MWe
Gravelines - Nord district - (03/1980 – 08/1985)	6 - REP	910 MWe
Dampierre - Loiret district - (03/1980 – 08/1981)	4 - REP	890 MWe
Tricastin - Drôme district - (05/1980 – 06/1981)	4 - REP	915 MWe
Saint-Laurent-des-Eaux B - Loir-et-Cher district (01/1981 – 06/1981)	2 - REP	915 MWe
Blayais - Gironde district - (06/1981 – 05/1983)	4 - REP	910 MWe
Chinon B - Indre-et-Loir district - (11/1982 – 11/1987)	4 - REP	905 MWe
Cruas - Ardèche district - (04/1983 – 10/1984)	4 - REP	915 MWe
Paluel - Seine-Maritime district - (06/1984 – 04/1986)	4 - REP	1,330 MWe
Saint-Alban - Isère district - (08/1985 – 07/1986)	2 - REP	1,335 MWe
Flamanville - Manche district - (12/1985 – 07/1986)	2 - REP	1,330 MWe
Cattenom - Moselle district - (11/1986 – 05/1991)	4 - REP	1,300 MWe
Belleville - Cher district - (10/1987 – 07/1988)	2 - REP	1,310 MWe
Nogent-sur-Seine - Aube district - (10/1987 – 12/1988)	2 - REP	1,310 MWe
Penly - Seine-Maritime district - (05/1990 – 02/1992)	2 - REP	1,330 MWe
Golfech - Tarn-et-Garonne district - (06/1990 – 06/1993)	2 - REP	1,310 MWe
Chooz B - Ardennes district - (08/1996 – 04/1997)	2 - REP	1,455 MWe
Civaux - Vienne district - (12/1997 – 12/1999)	2 - REP	1,450 MWe
19 sites	**58 reactors**	**–**

** MWe: electrical megawatts.*

3.1

Nuclear fuels

PWR fuel assemblies remain in nuclear power plant reactors for a few years.

A 900 Megawatt reactor constantly draws on 157 fuel assemblies, each of which contains around 500 kg of uranium. The fuel used is mainly uranium oxide (UOX).

However, 22 reactors are licensed to load mixed uranium-plutonium oxide (MOX) and four reactors are now equipped to use ERU type fuel made of enriched recycled uranium.

The ILW-LL waste produced by reactors in the operating phase are mainly poison rods (absorber rod assemblies whose role is to reduce core activity during the first operating cycle) and control rods (absorber rod assemblies in which the absorber rods slide inside the fuel assemblies to control reactor power).

Strict criteria regarding wear mean that they must be replaced several times during the unit's operating life. The waste produced during dismantling operations primarily involves the metal structures, which, like the rod clusters, present surface contamination associated with high activity in the mass.

The conditioning assumption applied by EDF is to cut up the metal waste on site or at a central facility (ICEDA) and to embed it in cement inside concrete packages. The waste packages are then kept in disposal facilities.

This new facility should be in operation by 2014 at the Bugey site (Ain district).

Operation of these EDF power plants and the associated maintenance activities also generate VLLW and LILW-SL waste. This may include 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 carry fission products and/or corrosion products activated when they pass through the core.

With the exception of the burnable waste and scrap iron that can be melted down, which is sent to CENTRACO plants (Gard district), the EDF LILW-SL waste is conditioned on site at the power plants in concrete waste packages or in metal drums and container boxes which are respectively compacted and injected at the LILW-SL disposal facility in the Aube district.

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

The major maintenance operations performed (replacement of the reactor vessel heads on 54 reactors) or scheduled on the nuclear reactors (notably the replacement of the steam generators of 34 of the 900 Megawatt reactors) produces significant volumes of waste. Within the framework of this *National Inventory*, the LILW and VLLW facilities in the Aube have been chosen to dispose of the waste from the steam generators, accepting that the added value of all or part of these components is also to be studied.

Graphite sleeve and GCR fuel rod

Decommissioned reactors

Sites	Type	Number of reactors
Chooz (Ardennes district)	PWR	1 reactor
Brennilis (Finistère district)	LWR	1 reactor
Saint-Laurent-des-Eaux (41) (Loir-et-Cher district)	GCR	2 reactors
Chinon (Indre-et-Loire district)	GCR	3 reactors
Bugey (Ain district)	GCR	1 reactor
Creys-Malville (Isère district)	FBR	1 reactor/fast breeder reactor

Decommissioned reactors

EDF operated six former generation gas-cooled graphite-moderated reactors (GCRs) developed by the CEA on the Chinon (Indre-et-Loire district), Saint-Laurent-des-Eaux (Loir-et-Cher district) and Bugey (Ain district) sites for which dismantling operations are under way and for which the resulting waste is listed under the current electricity production activity.

These units 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, scheduled after 2020. On the other hand, the sleeves, which have been removed and are stored in silos on the Saint-Laurent-des-Eaux (Indre-et-Loire district) site and at the Marcoule (Gard district) and La Hague (Manche district) sites, are counted as waste. The conditioning assumption applied for this existing and future waste is cementation in 10 cu. m concrete containers.

The decommissioned reactors are producing clean-up and/or dismantling waste as progress is made on the various phases of the dismantling process.

Finally, the Irradiated Materials Workshop (AMI) at the Chinon (Indre-et-Loire district) plant, where assessments of irradiated structures are carried out, also produces some waste.

3.1

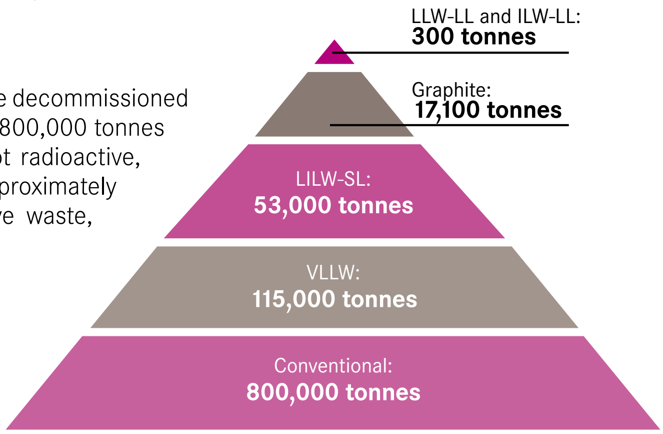
Waste produced from dismantling 9 decommissioned reactors

(source: information report on the demolishing of EDF nuclear power stations – February 2012)

A few figures:

In total, the demolishing of nine decommissioned reactors will generate around 800,000 tonnes of conventional waste, i.e. not radioactive, which will be recycled, and approximately 180,000 tonnes of radioactive waste, the majority with a short life.

VLLW: very-low-level waste
LILW-SL: short-lived low and intermediate-level waste
LLW-LL: long-lived low level waste
ILW-LL: long-lived intermediate-level waste



3.1.3
Spent fuel treatment

When withdrawn from the reactor, UOX type spent fuel contains 95% uranium and approximately 1% plutonium (10% for the MOX type spent fuel).

These are recoverable radioactive materials.

Spent fuel processing consists of recovering these materials and conditioning the final radioactive waste.

Pool E, storing spent fuel at the AREVA's La Hague (Manche district) processing plant

The operations carried out in the processing plants *(see boxes page 68)* can be broken down into three steps:

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

• **processing spent fuel assemblies** by:
- mechanically shearing the spent fuel assemblies into 35mm sections (known as "hulls"),
- chemically dissolving the spent fuel contained in the hulls using nitric acid,
- separating the dissolved uranium and plutonium by chemical extraction and purification, then conditioning;

Storage area at AREVA's UP2 800 R7 vitrification facility at La Hague (Manche district)

The UP1 plant at Marcoule (Gard district)

The first French spent fuel assembly processing plant, UP1, was commissioned at the Marcoule site in 1958 and was decommissioned at the end of 1997.

It was operated first by the CEA then by COGEMA (now AREVA) from 1976 for military purposes (plutonium extraction for weapons) and then civil purposes (processing fuel assemblies from the GCR series and PHÉNIX, and for experimental processing activities).

Clean-up operations are now under way. These include three programmes:

- decommissioning the facilities;
- dismantling (or demolition) of 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.

Aerial view of the Marcoule plant

La Hague (Manche district) treatment plant

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

In 1966, a second spent fuel assembly processing plant was commissioned at the La Hague site: UP2-400. It was operated by the CEA until 1976, and then by COGEMA (now AREVA). With an initial capacity of 400 tonnes of fuel per year, the UP2-400 plant started by processing spent fuel assemblies from the GCR series. It was then adapted to process PWR spent fuel assemblies.

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 assemblies.

In the early 1980s, AREVA began building two similar new plants with equivalent capacity (800 tonnes/year) which now process spent fuel to cater for French and foreign demand:

- UP3 was initially exclusively dedicated to spent fuel supplied by foreign customers (started up in 1990);
- UP2-800, commissioned in August 1994, which seamlessly took over from the UP2-400, decommissioned on 1st January 2004.

3.1

ILW-LL compacted package (CSD-C)

HLW vitrified package (CSD-V)

One HLW package contains approx. 400 kg of glass and 70 kg of waste.

- **treatment and conditioning of waste in stable forms,** appropriate to the activity and radioactive half-life of the elements they contain:

- the fission products and minor actinides are incorporated into glass matrices, poured into a stainless steel container (CSD-V); this waste makes up the majority of the HLW waste,
- for the PWR fuels, the metal components (cladding tubes, spacer grids and end caps) used to contain and assemble the fuel pellets, are now decontaminated, compacted and conditioned in standard compacted waste containers (CSD-C). Previously this cladding waste was mixed in a cement matrix. Compacting enables the waste disposal volume to be optimised. These two waste families make up the majority of the ILW-LL waste,
- the cladding waste from the GCR series is currently stored in silos at La Hague (Manche district) or Marcoule (Gard district) and will be recovered before 2030, probably to be conditioned in a cement matrix.

The waste from operation and maintenance is conditioned in different types of containers depending on their nature, level of activity and their management solution. In general, the solid ILW-LL waste (tools, gloves, filters, etc.) is compacted and put into drums; the methods for conditioning the sludge from waste treatment plants have changed over time. Initially, the sludge was embedded in a bitumen matrix. Optimisation of the conditioning processes and changes to constraints relating to safety led to the development of procedures for embedding the sludge in cement or drying and compacting it.

The LILW-SL waste is disposed of at the LILW-SL disposal facility (Aube district). It may first be treated at the CENTRACO plant (Gard district) by incineration or melting down, according to the physical and chemical nature.

The VLLW is conditioned in big bags or metal containers to be transferred and disposed of at the VLLW disposal facility (Aube district).

3.1.4
Waste treatment installations and maintenance centres

Running the various facilities that handle radioactivity entails related but mandatory industrial support operations: treating the waste arising from facility operation 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 especially concerns the nuclear power sector.

Steel ingot

Waste treatment centres

SOCODEI/CENTRACO at Marcoule (Gard district) 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 the liquid waste produced by nuclear facilities, research laboratories and hospitals. The resulting ash and clinker is rendered inert and conditioned in packages for disposal at the LILW-SL facility in the Aube. The same applies to the ingots produced by melting the metal waste.

Following a smelter accident on 12 September 2011, the installation was shut down, and its restarting is subject to license both for melting and incineration.

STMI and SOCATRI in Bollène (Vaucluse district) specialise in decontaminating radioactive material via conversion, conditioning and disposal operations. They thus produce radioactive waste. Andra uses part of the SOCATRI facilities to store long-lived waste that cannot currently be accommodated in its repositories, or SOCODEI, for the short-lived waste pending disposal.

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

Maintenance centres

Specialised companies provide maintenance for major facilities and/or decontamination of certain equipment.

These maintenance centres generally hold more limited quantities of waste than the waste treatment centres, most of which is intended for the LILW-SL disposal facility in the Aube.

The BCOT (Tricastin Operational Hot Point), in Bollène (Vaucluse district), carried out maintenance operations and disposal of contaminated equipment from EDF reactors, mainly reactor vessel heads, for which the replacement programme is now finished.

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

3.1

3.1.5
Inventory of radioactive material and waste at the end of 2010, 2020 and 2030

Waste stock by category

Waste stock in cu. m conditioned equivalent*

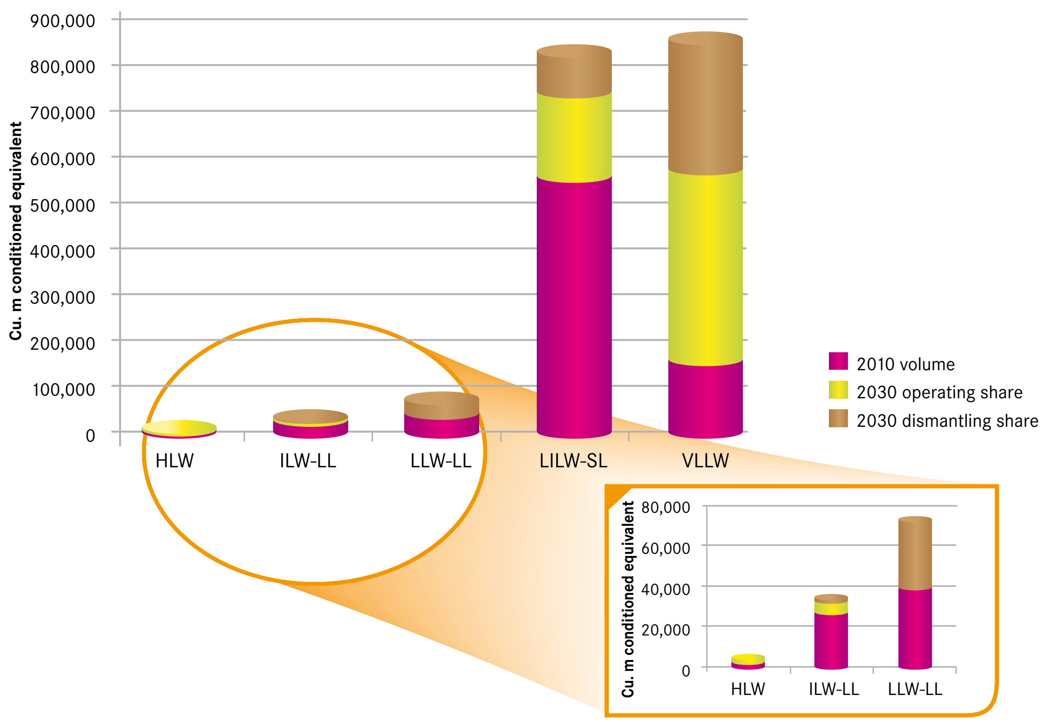
Category	Volume at the end of 2010	Forecast volume 2020	Forecast volume 2030
HLW	2,300	3,600	4,900
ILW-LL	27,000	31,000	34,000
LLW-LL	39,000	40,000	73,000
LILW-SL (including T-LILW-SL)	557,500	677,000	828,000
VLLW	159,000	437,000	857,000
Total	**~785,000**	**~1,190,000**	**~1,800,000**

** The figures are rounded up to the nearest hundred cu. m for HLW waste and to the nearest hundred or thousand cu. m for the other waste.*

With regard to waste from the COMURHEX plant in Malvési (Aude district), for which the long-term management mode is being decided *(see page 60)*, the volumes are as follows:

Category	Volume at the end of 2010	Forecast volume 2020	Forecast volume 2030
UCTR	600,000	635,000	688,000

Dismantling part at end 2030



Waste from SuperPhénix dismantling

Dismantling of the SuperPhénix will generate around 473,000 tonnes of waste, of which the majority (85%) is non-radioactive (metal, rubble, etc.) that will be recycled by the appropriate methods.

The radioactive waste is divided into:

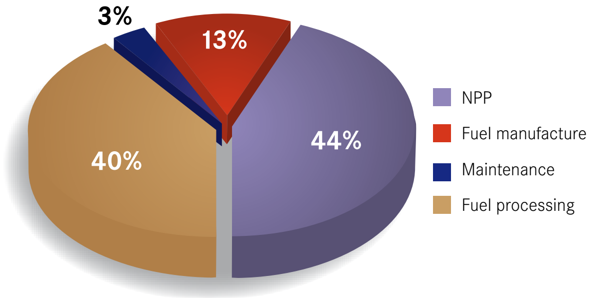
- a very small part of ILW-LL waste (approximately 4 tonnes) made up of the reactor control bars;
- VLLW or LILW-SL waste resulting from dismantling operations (reactor equipment, concrete, etc.) for around 10,000 tonnes. This waste will be evacuated to the Andra facilities, after fifty year's decay in the ICEDA storage facility at Bugey (Ain district) for those too active to be disposed of immediately (waste from the reactor vessel);
- very low activity cement blocks from sodium treatment. This treatment consists of transforming sodium into sodium hydroxide. This sodium hydroxide is then used as "mixing water" for the production of the one cubic metre poured concrete blocks.

This procedure makes the very low radioactive sodium hydroxide inert and confines it.

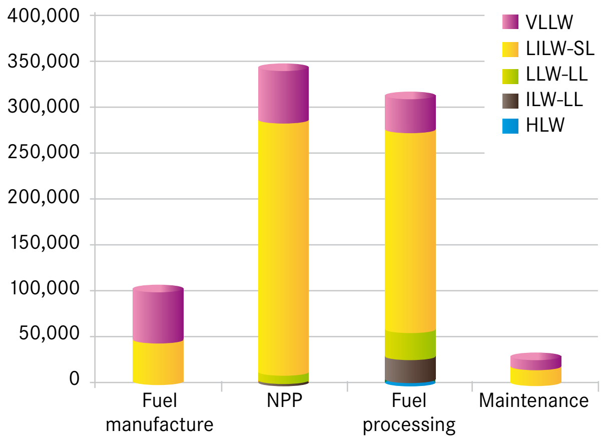
These blocks, representing a mass of 63,000 tonnes, are stored on the site, in a building specially designed for this purpose and under permanent monitoring.

Distribution per activity at the end of 2010

Distribution of volumes per activity at the end of 2010



Nature of the waste produced per activity at the end of 2010



Distribution of waste stocks per activity at the end of 2010 in cu. m conditioned equivalent*

Catégorie	Fuel manufacture	NPP	Fuel processing	Maintenance
HLW	0	0	2,300	0
ILW-LL	460	1,400	25,100	1
LLW-LL	10	9,100	29,900	0
LILW-SL (including V-LILW-SL)	46,000	276,000	220,000	16,000
VLLW	55,000	56,800	35,400	11,700

** The figures are rounded to tens or hundreds of cu. m for the HLW, ILW-LL and LLW-LL waste and to the hundreds or thousands for the other waste.*

The waste from the COMURHEX plant in Malvési (Aude district) is to be added to this total of 600,000 cu. m of waste (UCTR), representing 100 Terabecquerels coming from the "fuel manufacturing" activity, the category of which is being defined *(see page 60)*.

3.1

Georges Besse plants (Drôme district)

The Georges Besse I plant, operated by EURODIF, produces enriched uranium using the gas diffusion process. Its maximum enrichment capacity is 10.8 million SWUs* per year. Inaugurated in 2010 on the Tricastin site, the Georges Besse II plant will progressively take over from the current enrichment plant. This new plant comprises two production units that will reach a capacity of around 7.5 million SWTs by 2016-2018 and will use a new gas centrifuge technology.

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

The current plant will continue to produce in parallel until its scheduled decommissioning in 2013.

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

Stock of materials

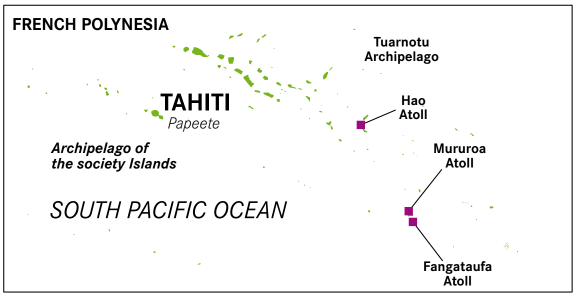
The radioactive materials at the end of 2010 as well as the production forecasts at the end of 2020 and end of 2030 are presented in the table. The production scenario for 2020 and 2030 is the same as that used for waste.

Stock of materials

Material	Mass (tML)		
	2010	2020	2030
Mixed uranium-plutonium fuel (MOX) in use in nuclear power plants	299	490	380
Spent mixed uranium-plutonium fuel (MOX), awaiting processing	1,287	2,400	3,800
Spent FBR fuel from SuperPhénix, awaiting processing	104	104	104
UOX fuel in use in nuclear power plants	4,477	4,340	3,650
Spent UOX fuel, awaiting processing	12,006	11,450	12,400
ERU (Uranium from treatment and then enriched) fuel in use in nuclear power plants	156	290	290
Spent ERU fuel, awaiting processing	318	1,050	1,750
Plutonium	78	53	51
Thorium	7	0	0
Depleted uranium	271,305	345,100	454,100
Enriched uranium	2,941	2,330	2,750
Uranium from spent fuel after processing	24,100	40,020	40,020
Mine-extracted natural uranium	15,900	25,000	25,000

3.2
Defence

This economic sector groups together activities from the research, production and experimentation centres working for the nuclear deterrent force and the different armed forces (Navy, Air Force, Army, etc.) and the French Armament Procurement Agency (DGA).



3.2.1 Research, production and experimentation centres working for the nuclear deterrent force

This concerns all the activities of the nuclear deterrent centres of the Military Applications Division (DAM) of the CEA, and the DAM nuclear propulsion installations at Cadarache.

CEA/DAM installations

The CEA's Military Applications Division (DAM) designs, manufactures and services France's Defence System nuclear warheads. It also dismantles nuclear weapons withdrawn from service.

In addition, it is in charge of the design and development of nuclear steam generators for the French Navy's fleet and manufacturing reactor cores for these steam generators.

The sites involved in the weapons and steam generator activities are classified as Secret Basic Nuclear Installations (INBS).

3.2

Valduc site (Côte-d'Or district)

The Valduc site produces some components of nuclear weapons. It processes the radioactive materials (plutonium, uranium and tritium) and also carries out research on materials.

Its activities produce waste that is contaminated with alpha emitters and with tritium. The Valduc ILW-LL waste comprises various technological wastes, conditioned in metal drums and sent to Cadarache (Bouches-du-Rhône district).

The sludge and concentrate packages in metal drums, previously produced by the effluent treatment station of the centre, are stored on the site pending their transfer to Cadarache (Bouches-du-Rhône district). The effluent from the centre is currently conditioned and disposed of at the LILW-SL disposal facility (Aube district).

The LILW waste is various metal and technological waste conditioned in 200 litre drums or in 5 cu. m metal container boxes.

The VLLW waste produced is mainly waste from operating. Note that there is 9,000 cu. m of VLLW contaminated ground from remediation of an area of the site. The Valduc site also produces tritium waste, the most active and gas discharging of which are conditioned in 200 litre drums and stored on the Valduc site.

Bruyères-le-Châtel site (Essonne)

Since it was set up, Bruyères-le-Châtel site has 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. The installations of this centre are being dismantled and mainly produce VLLW and LILW-SL waste.

Some specific and limited activities relating to physics and analysis are still carried out at the site.

The other sites

Explosive tests involving uranium depleted isotope-235 are carried out at Moronvilliers site (Marne district). Similarly, explosive test experiments have been carried out in the past at the CESTA centre (Gironde district), some of which also used uranium depleted in isotope-235.

For several years, the main role of the CESTA has been to develop the industrial architecture of the nuclear deterrent.

There is mainly VLLW waste found on these sites (metal waste, varied technological waste and waste from dismantling or improvements) contaminated with uranium.

The Gramat centre (Lot district), previously managed by the DGA, joined the CEA/DAM in January 2010; it is a centre of expertise for Defence in terms of vulnerability and the efficiency of weapons with regard to conventional and nuclear weapon attacks. This centre also uses depleted uranium.

The waste present on this site is VLLW waste: slightly contaminated metal waste (steel) and operating waste.

Disposal of tritium waste

At the end of 2010, the volume of tritium waste present in France was around 4,600 cu. m.

Currently most of this waste is generated by defence activities.

In compliance with the recommandations for the disposal of tritium waste without a disposal solution produced by the CEA within the PNGMDR 2007-2009 framework, the CEA/DAM has started construction of a first storage facility at Valduc to increase the capacity for holding tritium waste from installations working for the nuclear deterrent force.

This first building is scheduled to be commissioned at the end of 2012.

Storage of tritium waste at the Valduc site (Côte-d'Or district)

Some installations operated by AREVA on behalf of the DAM are intended for the manufacture of components for nuclear warheads. This is the case for the CELESTIN reactors, the Tritium extraction facility at Marcoule (ATM) (Gard district) and the recycling and production plant (ERU) at Pierrelatte (Drôme district) for which production has been stopped.

Finally, the DAM nuclear propulsion facilities at Cadarache (Bouches-du-Rhône district) are used to develop, qualify and provide maintenance for certain systems and equipment for nuclear steam generators for the French Navy nuclear fleet.

Facilities that have stopped operating

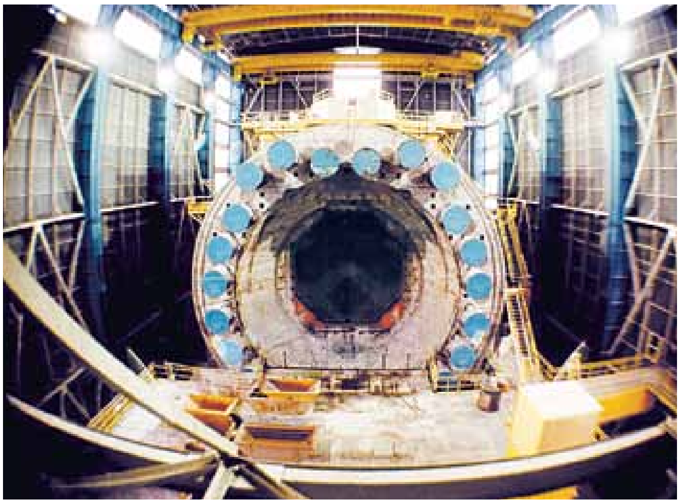
Since 2004, the CEA has acted as Project Owner for dismantling the UP1 plant, which extracted and purified plutonium for military use before treatment of certain irradiated fuel assemblies from the GCR series of reactors.

The waste from fuel treatment operations for the nuclear deterrent force is included in the statements in this paragraph.

Since the production of fissile material based on highly enriched uranium for Defence purposes has ceased, leading to the closure of four enrichment plants, the CEA/DAM has acted as Project Owner for dismantling the Pierrelatte enrichment plants (Drôme district).

It also ensures dismantling of the G2 and G3 GCR reactors at Marcoule (Gard district) which manufactured plutonium for the nuclear deterrent force.

The same applies to the PAT and RNG reactors at Cadarache (Bouches-du-Rhône district) for which the CEA/DAM acts as Project Owner for dismantling.



Dismantling gas-cooled graphite-moderated reactors G2 and G3 at Marcoule (Gard district)

The Pacific Test Centre

The waste from nuclear experiments carried out in the past is disposed of on the sites of Mururoa, Fangataufa and Hao in French Polynesia *(see chapter 4)*.

3.2

3.2.2
French Defence Establishments

This activity sector covers the professional activities related to French Defence (excluding the research, production and experimentation centres working for the nuclear deterrent centres covered in the previous chapter) and that hold radioactive waste, whether directly attached to the Ministry of Defence or working on their behalf: The Air Force, Army, Navy, Armament Procurement Agency (DGA), Armed Forces Health Services (SSA) and the French Gendarmerie.

Note that since 1st January 2009, the French Gendarmerie is no longer attached to the Ministry of Defence but to the Ministry of the Interior.

However, the type of waste is the same even if the Ministries change. In the remainder of this chapter, the gendarmerie is therefore attached to the French defence establishments.

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 French Defence establishment (around one hundred sites listed).

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. This is the case, for example, with the Châteaudun (Eure-et-Loir district) site for the Air Force or the Saint-Priest (Rhône district) site for the Army.

Eventually there will be two inter-forces waste collection centres: the Châteaudun (Eure-et-Loir district) site for waste containing thorium and the Neuvy-Pailloux (Indre district) site for other radioactive waste.

The radioactive waste sorting and disposal site at Neuvy-Pailloux (Indre district) is being built to replace the Saint-Priest (Rhône district) site, which is saturated and does not comply with the changes in the radiological protection regulations.

This centre will have the role of sorting and treatment of the French Defence waste, to store it for around 25 years and to condition it as required by Andra to be taken over in a final outlet.

This storage centre is scheduled to be commissioned in 2013. The already operational site at Châteaudun (Eure-et-Loir district) will continue to only store thorium waste until it is taken over by Andra.

Submarine Le Redoutable

French Defence harbours

The military harbours at Brest/Île Longue (Finistère district), Cherbourg (Manche district) and Toulon (Var district) produce radioactive waste, mostly VLLW, coming from construction, operation, maintenance and dismantling operations of submarine and aircraft carrier steam generators.

The reactor units of submarines being dismantled are stored at Cherbourg (Manche district).

Submarine Le Redoutable: *cross section of the submarine's reactor unit*

DCNS and DGA establishments

DCNS manufactures components for nuclear steam generators for the French Naval fleet in collaboration with AREVA.

The DGA site at Bourges (Cher district) puts radioactive waste resulting from experiments and tests carried out on weapons containing isotope-235 into containers.

Waste produced by French Defence centres

The 106 sites producing and/or holding radioactive waste have been listed.

The *table opposite* details the 28 types of waste listed on these sites.

This waste mainly consists of small items of equipment incorporating luminescent paint containing radium or tritium (compasses, plates, sights, dials, etc.).

Most of these objects are considered as spent sealed sources *(see special report 2).*

Type of waste listed by the French defence centres

Type of waste	Radionuclides
Compasses	^{3}H or ^{226}Ra
Sighting devices	^{3}H or ^{226}Ra
Dials, indicators	^{3}H ou ^{90}Sr or ^{226}Ra
Radio-luminescent plates	^{3}H or ^{226}Ra
Electronic tubes	^{3}H
Electronic tubes	^{60}Co, ^{63}Ni, ^{137}Cs
Electronic tubes	U, Pu, ^{226}Ra
Control devices	^{14}C
Control devices	^{90}Sr
Control devices	Pu, ^{241}Am, ^{226}Ra
Metal parts	alliages Mg-Th
Lightning conductors	^{226}Ra or ^{241}Am
Smoke detectors	^{241}Am
Technological waste	^{3}H
Technological waste	^{60}Co, ^{137}Cs
Technological waste	Th, ^{241}Am, ^{226}Ra
Laboratory waste	^{3}H
Laboratory waste	^{14}C
Laboratory waste	^{60}Co, ^{137}Cs
Laboratory waste	Th, U, Pu, ^{241}Am
Laboratory samples	Th, U, Po

3.2.3
Inventory of radioactive material and waste at the end of 2010, 2020 and 2030

Waste stock by category

Practically all the tritium waste is produced by the Defence sector. Around 98% of the waste that will be produced between now and the end of 2030 will be from installations performing work for the nuclear deterrent forces.

Volume of waste per category in cu. m conditioned equivalent* (excluding spent sealed sources)

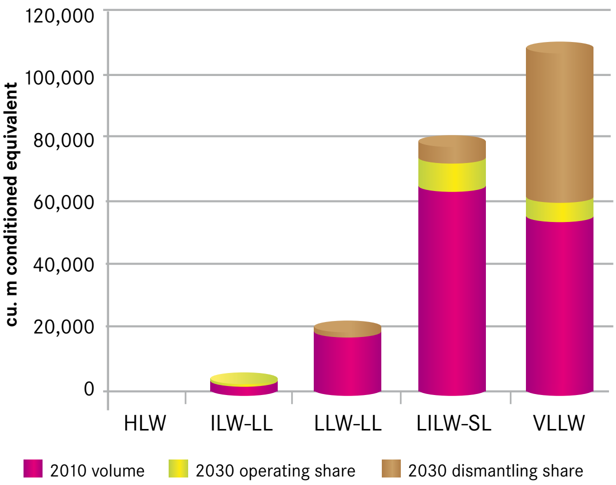
Category	Volume at the end of 2010	Forecast volume 2020	Forecast volume 2030
HLW	230	230	230
ILW-LL	3,000	3,000	3,000
LLW-LL	18,500	19,000	20,000
LILW-SL	60,200	65,500	71,500
VLLW	55,000	96,000	108,500
T- LILW-SL	4,500	6,100	7,400
Total	**~ 141,000**	**~ 190,000**	**~ 210,000**

** The figures are rounded up to the nearest ten cu. m for HLW waste and to the nearest hundred or thousand for the other waste.*

Volume of spent sealed sources at the end of 2010

Category	cu. m conditioned equivalent
HLW-LL	24
LILW-SL	1
VLLW	25
T- LILW-SL	7

Dismantling share at the end of 2030



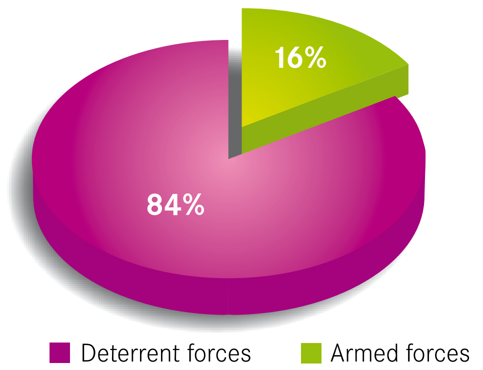
3.2

Distribution per activity at the end of 2010

More than 80% of the Defence waste is produced by the research, production and experimentation installations working for the nuclear deterrent forces.

Less than 0.1% of the volume of waste from the armed forces concerns objects considered as spent sealed sources.

Volume of waste at the end of 2010 distributed per activity (excluding spent sealed sources)



Distribution in cu. m conditioned equivalent*

Category	Armed forces	Deterrent forces
HLW	0	230
ILW-LL	0	3,000
LLW-LL	700	17,800
LILW-SL	18,900	41,500
T- VLLW	100	4,400
VLLW	2,600	52,500

** The figures are rounded up to the nearest ten or hundred cu. m.*

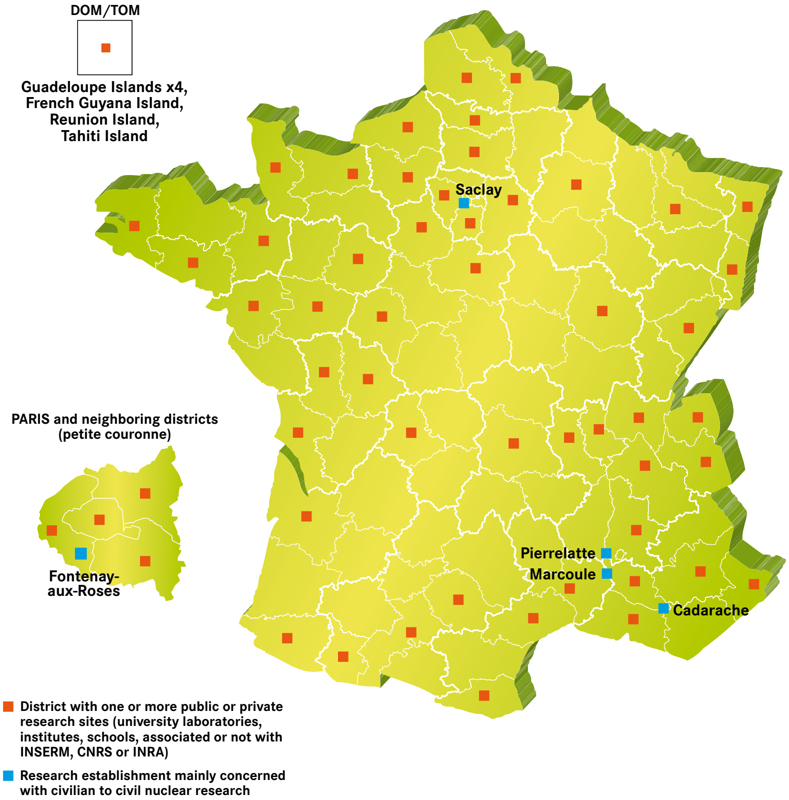
Stock of materials

Material	Mass (tonnes)		
	2010	2020	2030
French Defence fuel	146	218	284

3.3 Research

The research sector covers all research activities, excluding those carried out for the Defence sector, which are included in that sector. Research activities for the nuclear power sector and the medical sector are included.

Research laboratory



This sector includes the Atomic Energy Commission (CEA) civil research installations and establishments, and all the public or private research establishments. Some of these establishments, excluding the CEA, use radioactivity mostly for characterisation and do not carry out research in the nuclear sector, and in particular the nuclear power activity.

3.3

3.3.1 The civil research centres of the CEA

The nuclear power division of the CEA provides permanent support to the nuclear industry in France with a view to optimising existing nuclear power plants and the fuel cycle. It develops technical solutions for the treatment and conditioning of radioactive waste.

The 2006 Act scheduled that the CEA produce a 4th generation type reactor prototype (ASTRID reactor) and to pursue research as part of a European programme, on controlled thermonuclear fusion, with the very long-term objective of producing electricity. The CEA is responsible for the clean-up and dismantling of its own nuclear facilities. It also develops programmes regarding the impact of nuclear power on health and the environment.

The CEA operates 5 civil research centres. It runs many facilities, laboratories and research reactors as part of its R&D programmes. Management of its nuclear facilities produces waste similar to that of the other nuclear operators (maintenance operations waste, contaminated tools, etc.) although the waste is often more varied in nature. Its research activities on reactor operation and on spent fuel treatment generate the types of waste set out in *paragraph 3.1.*

The CEA's civil centres

Marcoule (Gard district)

The fuel processing activities of the Marcoule centre are described on *page 68*. The waste from fuel processing operations related to R&D activities is included in this paragraph.

The installations being operated at the Marcoule centre are dedicated to research and development of uranium preparation techniques, fuel processing using industrial processes, spent nuclear fuel processing (act of 28 June 2006), clean-up and dismantling techniques for nuclear installations at the end of their life and management of the most radioactive waste.

Two reactors are waiting dismantling:

- the Phénix reactor, built and operated by the CEA and EDF was a research tool for plutonium consumption and actinide incineration programmes. It was decommissioned in 2009 and is currently being prepared for dismantling;
- the G1 reactor, used for nuclear deterrent research purposes, was decommissioned and is under civil CEA responsibility.

Phenix plant at Marcoule (Gard district)

Cadarache (Bouches-du-Rhône district)

Activities at the Cadarache Centre are spread across a number of technological research and development platforms, mainly focusing on nuclear energy. For example, the ITER reactor was built at Cadarache. It should permit a major leap forward from existing facilities to the possibility of future electricity generating reactors based on fusion, by demonstrating the scientific feasibility of this process.

In addition, R&D activities are carried out at Cadarache aimed at optimising nuclear reactors and studying the behaviour of uranium or plutonium based fuels in different configurations (experimental reactor from FBR series now shut down: RAPSODIE, or from REP series: SCARABÉE, CABRI).

The site operates around twenty installations including R&D installations for nuclear fuels and irradiated materials, waste treatment installations and installations for the disposal of waste and materials.

Saclay (Essonne district)

The Saclay centre runs major facilities (LECI laboratory, reactors ORPHÉE and OSIRIS) for fundamental research and applied research geared to the requirements of the nuclear power industry.

Part of the waste produced is treated and conditioned at the Centre's support facilities: INB 72 for solid waste and INB 35 and STELLA for liquid waste. Other waste is transferred to Marcoule (Gard district) or Cadarache (Bouches-du-Rhône district) for treatment. The pilot EL2 and EL3 reactors of the heavy water series are to be dismantled.

View of STELLA and INB35 plants (Essonne district)

Fontenay-aux-Roses (Hauts-de-Seine district)

The Fontenay-aux-Roses centre is undergoing major restructuring: its nuclear research facilities, which have been decommissioned, are the subject of a clean-up 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 site included chemical engineering, fuel assembly treatment and the chemistry of transuranian elements.

3.3

Grenoble (Isère district)

The main facilities concerned by the clean-up and dismantling of the CEA centre at Grenoble (PASSAGE project) were permanently decommissioned according to the following calendar: Mélusine (1988), Siloé (1997), Siloette (2002), LAMA (2002) and STED (2003). The order for dismantling was received in 2004 for the Mélusine reactor, in 2005 for the Siloette and Siloé reactors, and in 2008 for the LAMA laboratory and the effluent and STED waste treatment station.

The clean-up and dismantling operations for all these facilities will be finished at the end of 2012. The declassification order for Siloette was obtained in 2007, for Mélusine in 2011, and for the other facilities, it will be obtained in 2013. Following declassification, some facilities will be kept, while others will be destroyed. The activities of the Grenoble centre are now focusing primarily on new computer and communication technologies, biotechnology, new energy technologies and nanomaterials.

Clean-up at the MÉLUSINE reactor in Grenoble (Isère district)

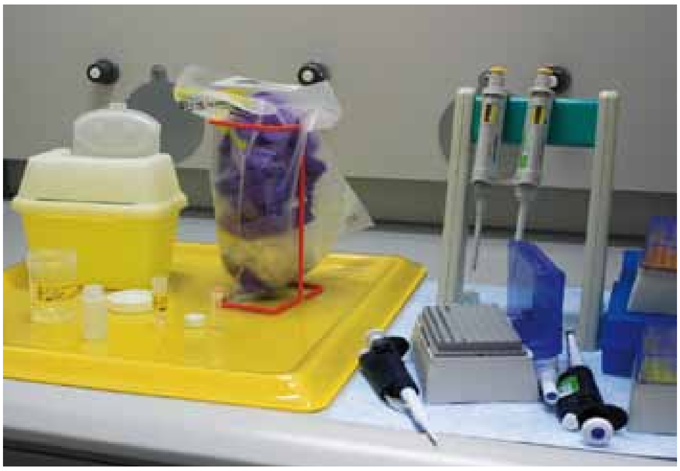
3.3.2
Research Establishments (excluding CEA)

This activity sector covers all the public and private research centres, together with the units of all the major organisations or industrial groups that are mainly or exclusively involved in research.

Many public and private establishments use radionuclides. Altogether, Andra has listed around 570 producers in the research sector at the end of 2010 (excluding the CEA).

These include:

- medical research laboratories or INSERM, attached to Medical or Pharmacological facilities, and based at hospitals or university teaching hospitals;
- CNRS laboratories or mixed research units associated to the CNRS, usually located within facilities, institutes or *Grandes Écoles*;
- units of the French National Institute of Nuclear Physics and Particle Physics (IN2P3), including the particle accelerators at Orsay (Essonne district) and Caen (Calvados district) (GANIL);
- the reactor belonging to the Laue-Langevin Institute (ILL) in Grenoble (Isère district) and the European Centre for Nuclear Research (CERN), on the border between France and Switzerland;
- private sector establishments such as SANOFI or L'Oréal;
- various decommissioned reactors and facilities (including the Strasbourg university reactor (Bas Rhin district)).



Research laboratory

In this sector, the most commonly found very short-lived radionuclides are phosphorus-32 and 33, sulphur-35, chromium-51 and iodine-125. In cellular and molecular biology, these are used to mark the molecules into which they are incorporated. For short-lived radionuclides, tritium is often used.

With regard to the long-lived radionuclides, carbon 14 is the most commonly used marker. These radionuclides are most often used in the form of unsealed sources (i.e. small liquid samples). After use, they become liquid waste, and they are generally entrusted to Andra to be forwarded to CENTRACO (Gard district) for treatment *(see paragraph 3.1)*.

Waste with a half-life of less than 100 days is left *in situ* to allow it to decay.

Waste from these research activities (excluding CEA centres) with a half-life greater than 100 days is VLLW and LILW-SL waste.

3.3.3
Inventory of radioactive waste at the end of 2010, 2020 and 2030

Waste stock by category

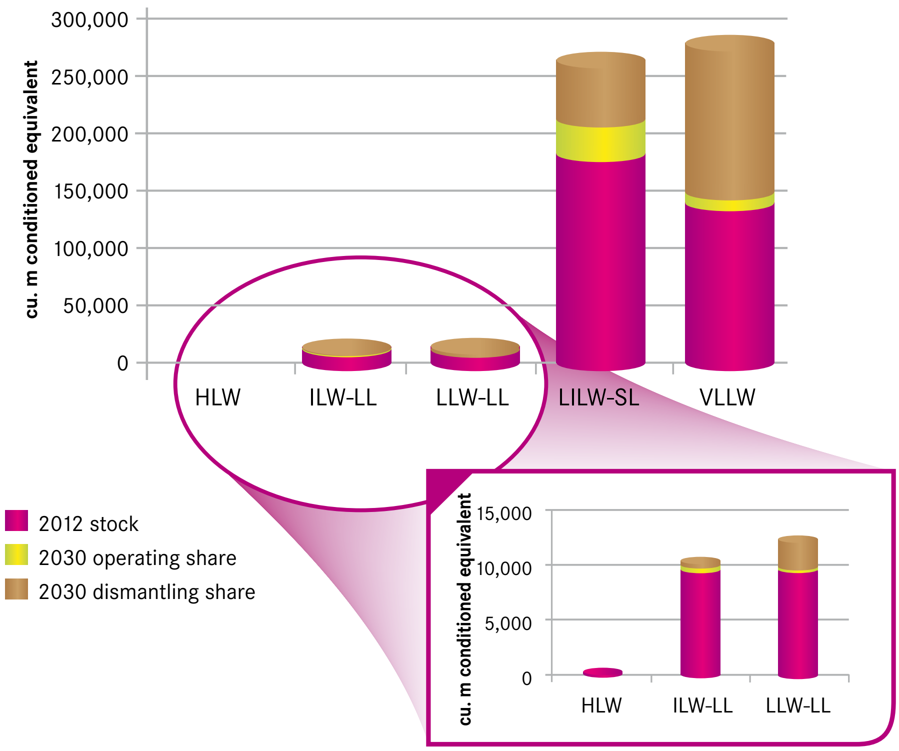
The forecast volumes do not take into account the tritium waste that will be produced from 2020 from the operation of ITER, as this installation is not yet licensed. The volume of spent sources considered as waste is in the order of one cubic meter conditioned equivalent; they are in the LILW-SL category.

Volume of waste per category in cu. m conditioned equivalent (excluding spent sealed sources)*

Category	Volume at the end of 2010	Forecast volume 2020	Forecast volume 2030
HLW	200	200	200
ILW-LL	9,600**	10,500	11,200
LLW-LL	9,600	9,600	12,400
LILW-SL (including T-LILW-SL)	182,000	224,000	263,500
VLLW	138,000	208,000	278,000
Total	**~ 340,000**	**~ 452,000**	**~ 565,000**

** The figures are rounded to the nearest ten cu. m for HLW waste and to the nearest hundred or thousand cu. m for other waste.*
*** Erratum january 2013.*

Dismantling share at the end of 2030

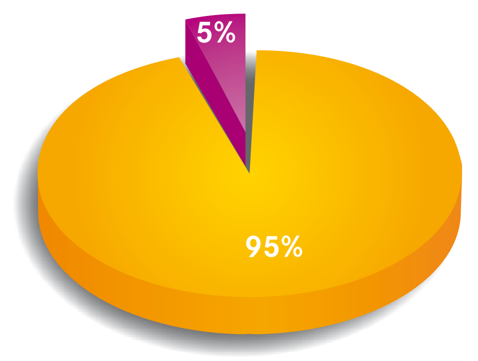


3.3

Distribution per activity

Almost 95% of the waste produced in the research sector is from nuclear power facilities.

Volume of waste at the end of 2010 distributed per activity (excluding sealed sources)



Distribution in cu. m conditioned equivalent*

Category	Research for nuclear power	Research for other sectors
HLW	200	0
ILW-LL	9,600	2
LLW-LL	9,600	30
LILW-SL	166,000	16,100
VLLW	136,000	1,900

** The figures are rounded up to the nearest ten cu. m for HLW, ILW-LL and LLW-LL waste and to the nearest hundred or thousand for the other waste.*

Stock of materials

Material	Mass (tML)		
	2010	2020	2030
Spent fuel from civil research reactors, awaiting processing (Including Phénix)	53	14	9
Plutonium from spent fuel after processing	2	2	2
Depleted uranium	175	175	175
Enriched uranium	14	14	14
Mine-extracted natural uranium	13	13	13
Spent metal fuel, awaiting processing	15	15	15

3.4 Industry apart from nuclear power

3.4.1 Industry using radioactivity

This activity encompasses the manufacturing and industrial use of radioactive sources (sealed and unsealed) outside the medical sector.

It also includes the manufacturing and use of miscellaneous devices that use radioactive products (lightning conductors, smoke detectors, etc.) or the properties of radioactivity (monitoring sources for compliance, maintenance, etc.).

Radium lightning conductor

The life of a sealed source is limited and makes it unusable after a few months or a few years, depending on the half-life of the radionuclide considered. It is not always considered as ultimate waste.

Previously, order 2002-460 of 4 April 2002 required the users of sealed sources to have the expired or obsolete sources collected within a maximum period of 10 years, unless they received a dispensation from the ASN.

Now, article R. 1333-52 of the French Code of Public Health, introduced by order 2007-1582 of 7 November 2007, specifies that by special dispensation this obligation is not applicable if the characteristics of the sealed source allow for its decay on the site where it has been used (mainly in the case of low level activity and short half-life).

Additionally, article R. 4452-12 of the French Labour Code requires that all sealed sources 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 LILW-SL disposal facility in the Aube district, provided that they meet the facility's safety requirements *(see special report 2).*

3.4.2 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 of low or very-low-level.

3.4

Sources for industrial irradiators

Sources for gammagraphy

RHODIA Plant – LLW-LL waste

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 high or low natural nuclide 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 is described in *report 3*.

The currently listed management solutions for this type of waste are the VLLW disposal facility (Aube district), the future radium waste disposal centre or the conventional disposal centres when an impact study has shown that there is no effect on humans or the environment. Some waste was disposed of close to the installations in the past *(see chapter 4)*.

3.4.3
Inventory of radioactive waste at the end of 2010, 2020 and 2030

Waste stock by category

Waste stock at the end of 2010, 2020 and 2030 in cu. m conditioned equivalent*
(excluding spent sealed sources)

Category	Volume at the end of 2010	Forecast volume 2020	Forecast volume 2030
ILW-LL	1	1	1
LLW-LL	19,200	20,700	27,800
LILW-SL (including V-FMA-SL)	17,800	18,000	18,200
VLLW	8,300	21,200	32,400
Total	**~ 45,300**	**~ 59,900**	**~ 78,400**

* *The figures are rounded up to the nearest hundred or thousand for waste other than ILW-LL.*

Volume of spent sealed sources at the end of 2010 in cu. m conditioned equivalent per category

Category	Volume
HLW-LL	121
ILW-LL	125
VLLW	21
Total	**266**

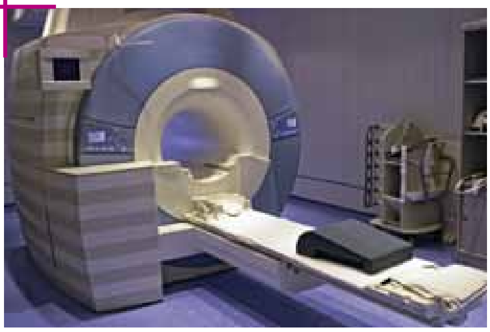
Stock of materials

Material	Mass (t)		
	2010	2020	2030
Suspended particulate matter (SPM - by-products from rare earth elements ore treatment)	23,454		
Thorium	9,400	9,334	9,224

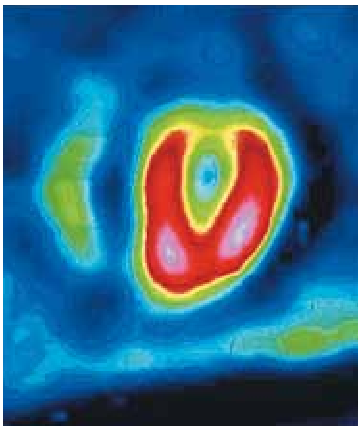
3.4

3.5 Medical

This economic sector includes all the public and private establishments that use radionuclides for medical analysis or treatment. Medical research centres are not included as they form part of the research economic sector.



Scanner



Cardiac scintigraphy

This sector covers three major areas:

- biological analysis, carried out *in vitro* on biological samples for the purposes of diagnosis;
- medical imaging techniques, used in diagnosis;
- therapeutic applications, carried out *in vitro* or *in vivo*.

These establishments mainly use unsealed sources, i.e. radionuclides contained in liquid solutions.

The main users of these sources are nuclear medicine departments and their associated laboratories. The same establishments also use sealed sources for radiotherapy, brachytherapy and for calibrating the instruments used to measure the activity of the products injected in the patients *(see special report 2)*.

The liquid waste products are managed in two different ways depending on the half-life of the radionuclides they contain:

- decay on site for those with very short half-live duration;
- treatment at CENTRACO (Gard district) and disposal in Andra centres for the longer half-life durations.

Apart from these sources, solid waste is also managed either by decay on site then stored in a conventional facility or directly at an Andra centre after treatment and conditioning.

Waste inventories

At the end of 2010, the volume of waste produced by these medical activities, excluding spent sealed sources, was 8,558 cu. m. Almost all this waste is in the LILW-SL category.

3.5

Legacy situations

Legacy situations

The modalities concerning management of radioactive waste have evolved over time. This chapter lists the various sites containing radioactive waste resulting from management choices made when the waste was initially dealt with. All the sites are covered by environmental monitoring, which enables to check that the impact linked to the waste is controlled, or if that is not the case, to take suitable steps to protect the environment and the populations.
Most of the sites mentioned here are covered by a data sheet in the Geographical Inventory. The quantities of waste set out in this chapter are not included in the statements set out in chapters 2 and 3.

4.1 Conventional waste disposal facilities

In the past, conventional waste disposal facilities, now known as waste disposal facilities (WDF), were regularly or occasionally used to dispose of waste containing small quantities of radioactivity at levels of a few becquerels per gram.

That type of waste does not involve any radiological protection issues, so it was possible to dispose of it via a conventional solution, under the conditions for the time and in compliance with the regulations and instructions in force.

However, the sites thus used are set out in the *National Inventory* to ensure its exhaustiveness.

Some of the waste formerly managed in these conventional disposal facilities came from CEA research centres (dismantling waste, earth and rubble from various cleaning-up operations, etc.).

4.

Thirteen sites of this type are listed in the *National Inventory*. They are in the following municipalities:

- Angervilliers in the Essonne district;
- Bailleau-Armenonville in the Eure-and-Loir district;
- Bellegarde in the Gard district;
- Champteussé-sur-Baconne in the Maine-et-Loire district;
- Freney in the Savoie district;
- Menneville in the Pas-de-Calais district;
- Monteux in the Vaucluse district;
- Pontailler-sur-Saone in the Cote-d'Or district;
- Saint-Paul-lès-Romans in the Drôme district;
- Saint-Quentin-sur-Isère in the Isère district;
- Solérieux in the Drôme district;
- Vif in the Isère district;
- Villeparisis in the Seine-et-Marne district.

Bellegarde (Gard district) and Villeparisis (Seine-et-Marne district) are the only sites listed above that are still used for disposal of waste with technically-enhanced naturally occuring radioactivity (TENORM), stemming from industries other than nuclear power *(see special report 3)*, under conditions that comply with the licenses covering use of these facilities and in conformity with the ministerial circulars of 10 June 2003 and 25 July 2006 [I].

[I] *Circular of 25 July 2006 BPSPR/2006-217/HLW and circular DPPR of 10 June 2003.*

4.2
Legacy on-site disposal

In the past, some types of radioactive waste were disposed of near nuclear facilities or plants. The disposal areas usually take the form of mounds, backfills or lagoons. The sites identified in this chapter are those that the operator or the owner of the radioactive waste did not envisage cleaning up at the date of their declaration to the *National Inventory*.

At the end of 2010, the sites of this type listed in the *National Inventory* are the following:

- the A126 motorway in Chilly-Mazarin (Essonne district): VLLW waste from dismantling of the former plant in Le Bouchet (Essonne district), with average levels of radium and uranium comparable to those found in natural surroundings (up to 3 becquerels per gram), was used on the motorway construction site in the 1970s;
- Montbouchet mound (Essonne district): in particular, that mound contains VLLW waste generated when cleaning up the former Le Bouchet plant between May 1975 and March 1977;
- Pierrelatte mound (Drôme district): fluorine waste from the COMURHEX plant was buried in that earth mound between 1964 and 1977;
- Bugey mound (Ain district): this artificial mound, made up of miscellaneous natural excavation materials, contains 130 cu. m of ion exchange resins; the measurements made have shown radioactivity levels of less than 0.3 becquerels per gram;
- Vernay lagoon in Loos-les-Lille (Nord district): this ore treatment site generated filtration sludge that was disposed of on the site;
- the port of La Pallice in La Rochelle (Charente-Maritime district): production residues from the RHODIA plant were used as landfill for the port;
- the site of the Chef-de-Baie plant in La Rochelle (Charente-Maritime district): solid residues were also used as backfill on the site of the plant.

The total quantity of waste disposed of on these sites is estimated at just over 130,000 cu. m.

Legacy disposal sites set up before 2000

In accordance with article 6 of the PNGMDR decree [II], investigations concerning the presence of legacy disposal sites for waste with very-low-levels of radioactivity, generated before 2000 and not declared to the *National Inventory*, are being carried out on the INBs and INBSs run by the CEA, AREVA and EDF. The investigation programme for these legacy disposal sites consists of 3 phases:

- listing: carried out for each nuclear site and drawn up on the basis of the documentation on waste management, past inquiries and environmental monitoring;
- analyse and audit of the sites with field inspections and evaluation of the monitoring systems;
- management modalities.

As set out in the decree issued for the PNGMDR order, an initial progress statement concerning the studies will be forwarded in mid-2012. As and when identified, the sites will be added to the *National Inventory*.

[II] *Decree No. 2012-542 of 23 April 2012 on application of article L. 542-1-2 of the Code of the environment and establishing the instructions concerning the National plan for management of radioactive materials and waste (PNGMDR).*

4.3
Disposal facilities for waste with technically-enhanced radioactivity

A certain number of sites producing waste with technically-enhanced naturally occuring radioactivity (TENORM) were identified in the 2009 edition of the *National Inventory* *(see special report 3)*.

The 2009 ASN report [III] listed other sites that could contain TENORM waste with low levels of activity.

For the present edition, some of the other sites, most of which are no longer in use, are considered as TENORM waste disposal facilities.

This mainly concerns the following types of sites:

• **disposal of phosphogypsum,** generated during production of phosphoric acid that was used to make fertiliser. These sites are no longer in use, and they are monitored:

- Anneville-Ambourville (Seine-Maritime district),
- Saint-Etienne-du-Rouvray (Seine-Maritime district),
- Rogerville (Seine-Maritime district),
- Douvrin (Pas-de-Calais district);

• **disposal of residues** from production of alumina:

- Gardanne (Bouches-du-Rhône district),
- Vitrolles (Bouches-du-Rhône district),
- Marseille (Bouches-du-Rhône district) (Aygalades, La Barasse-Saint-Cyr, La Barasse-Montgrand);

• **disposal of coal ash** from thermal power plants and not recoverable:

- La Grand-Combe (Gard district),
- Fuveau (Bouches-du-Rhône district),
- Arjuzanx (Landes district).

It is to be noted that some of the coal ash slag heaps are recovered for use in building materials (concrete) *(see special report 3)*.

4.3

[III] *ASN report of 20 July 2009 "Statement concerning management of waste containing technically- enhanced radioactivity".*
ASN report of December 2009 "Evaluation of exposure to ionising radiation in the industries and professional activities involving use of raw materials naturally containing radionuclides and not used for their radioactive properties: statement concerning application of the order of 25 May 2005 on such activities".

4.4 Defence disposal sites

Between 1966 and 1996, the French Government tested nuclear weapons on the Pacific experimentation site (CEP), on the Mururoa and Fangataufa atolls in the South Pacific, in French Polynesia.

These nuclear tests were initially carried out in the atmosphere (1966-1974), and then underground, in boreholes drilled vertically down into the rock of the coral reefs (1975-1987) or under the lagoons (1981-1996).

The waste disposed of *in situ* is set out in the Geographical Inventory.

Mururoa Atoll

4.5 Mining sites

Extraction of natural ores containing uranium (in open-cast or underground mines) is no longer carried out in France (the last mine was closed in 2001).

The physical and chemical treatment of the ores to selectively extract the uranium and precipitate it in the form of a solid, stable compound often called yellow cake led to production of residues with levels of radioactivity comparable to that of VLLW.

These residues, which are listed in the *National Inventory*, were disposed of using specific techniques on or near the former mining production sites. The plants in which these operations were carried out have all been closed down and dismantled.

The residue disposal facilities are covered by licenses and monitoring instructions drawn up to control classified facilities or mines.

Bellezane uranium mine (Haute-Vienne district)

During operation

After rehabilitation

The seventeen disposal facilities concerned are:

- Bauzot (Saône-et-Loire district);
- Bellezane (Haute-Vienne district);
- Bessines-sur-Gartempe - Brugeaud (Haute-Vienne district);
- Bessines-sur-Gartempe - Lavaugrasse (Haute-Vienne district);
- Bertholène (Aveyron district);
- Gueugnon (Saône-et-Loire district);
- Jouac (Haute-Vienne district);
- La Commanderie (Vendée and Deux-Sèvres district);
- La Ribière (Creuse district);
- Le Cellier (Lozère district);
- L'Escarpiere (Loire-Atlantique district);
- Les-Bois-Noirs-Limouzat (Loire district);
- Lodève (Hérault district);
- Montmassacrot (Haute-Vienne district);
- Rophin (Puy-de-Dôme district);
- Saint-Pierre-du-Cantal (Cantal district);
- Teufelsloch (Haut-Rhin district).

On some of these sites, VLLW waste linked to use or dismantling of ore treatment facilities or other front end facilities in the cycle was also disposed of *in situ*. The sites concerned are Bauzot (Saône-et-Loire district), Saint-Pierre-du-Cantal (Cantal district), Bessines-sur-Gartempe (Haute-Vienne district), Gueugnon (Saône-et-Loire district), Lodève (Hérault district), Jouac (Haute-Vienne district), L'Escarpiere (Loire-Atlantique district), and Les-Bois-Noirs-Limouzat (Loire district). Moreover, three sites managed by the Mining division at Crouzille (Haute-Vienne district) (AREVA, formerly CEA/COGEMA), were used in the 1970s and 1980s as a disposal facility for VLLW from various front-end establishments in the cycle: Fanay, Margnac and Peny (all in the Haute-Vienne district).

4.5

These twenty former mining sites are listed in the Geographical Inventory.

A statement of the long-term impact on health and the environment of the disposal facilities for these mining residues was forwarded by AREVA to the French ministry for the Environment in 2008 in application of article 10 of the order of 16 April 2008 [IV].

Furthermore, in 2010, the Pluralist Expertise Group (GEP) for the Limoges region submitted a report on the current and long-term impact of the mining operations. The report puts forward monitoring management options [V].

Lastly, in conformity with the circular of 22 July 2009 [VI], environmental statements are being carried out for all the mining sites under AREVA's responsibility, including the disposal facilities for treatment residues. A diagnosis of the sites without management systems is also in progress.

More generally, the MIMAUS [1] inventory (Memory and Impact of urAniUm Mines: Statement and Archives) sets out the most exhaustive list possible of the sites on which uranium ore exploration, extraction or treatment activities were carried out in metropolitan France. The sites without management systems will also be referenced in the database.

Moreover, waste from residues generated by the COMURHEX plant, are stored on the site in Malvési (Aude district). That waste is listed separately in the statements, whereas in the previous editions of the *National Inventory*, it was included in the family of uranium treatment residues from the former mining sites and as such was not shown in the statements.

A considerable proportion of that waste is only contaminated by natural uranium. Nonetheless, some legacy waste is contaminated by artificial radionuclides as a result of recycled uranium treatment, in Malvési (Aude district). The Malvési plant now only converts natural uranium.

1 *The MIMAUSA inventory can be consulted on the IRSN Internet site: http://mimaubdd.irsn.fr/Mimausa/*

[IV] *Order No. 2008-357 of 16 April 2008 on application of article L.542-1-2 of the Code of the environment and setting out the instructions regarding the National plan for management of radioactive materials and waste.*

[V] *"Recommendations for management of former uranium mining sites in France. From the sites in the Limoges region to the other sites, and from short to medium and long term", Final report drawn up by the Pluralist Expertise Group for the uranium mines in the Limoges region (GEP), September 2010.*

[VI] *Circular of 22 July 2009.*

4.6
Sites contaminated by radioactivity

The French inter-ministerial circular of 17 November 2008 [VII] gives the following definition of polluted sites:

“The term ‘site of radioactive pollution’ covers all sites, whether they have been abandoned or are in use, on which natural or artificial radioactive substances have been or are handled or stored under conditions such that the site presents risks health and/or the environment”.

The pollution found must be attributable to one or more radioactive substances, as defined in article L. 542-1-1 of the Code of the environment, i.e. a “substance that contains natural or artificial radionuclides whose activity or concentration levels justify radiological protection control”.

Decontamination site at Gif-sur-Yvette (Essonne district)

Thus the mere presence of radioactivity on a site, whether it is of natural or artificial origin, does not mean that it is a site of radioactive pollution as such.

In particular, a site can be simply marked by radioactivity, meaning that it shows detectable traces of natural or artificial radionuclides, without that fact entailing the necessity of envisaging any particular action, due to the absence of risk.

The origin of the pollution on each of these sites is set out as a reminder in the geographical data sheets.

They are mainly sites on which radium (or objects containing it) was worked, stored or commercialised during the first half of the 20th century *(see box on page 101)*.

The actual or supposed advantages of these objects were linked to the radioactive properties of radium (medical or paramedical objects) or stemmed from its properties (such as radio-luminosity).

[VII] *Circular of 17 November 2008 on management of certain types of radioactive waste and sites of pollution radioactive. Andra’s general interest mission.*

4.6

Policy on management of sites and ground polluted by radioactivity

Management of sites and ground polluted by radioactive substances lies within the general framework of the French national policy on management of sites that could be polluted by chemicals as set out in particular in the French Act of 30 July 2003 and in the texts issued on 8 February 2007 by the French ministry for the Environment. The specific case of management for sites and ground polluted by radioactivity is set out in the circular of 17 November 2008, and also in the ASN-DGPR-IRSN guide to management of sites and ground that could be polluted by radioactive substances, of December 2011.

In practice, if exposure is found, it is advisable to seek the actions to reduce such exposure that are suitable for, and in proportion to, the situation concerned. The management objectives must be defined in compliance with the principle of optimisation applicable concerning radiological protection, taking into account the characteristics of the pollution, the nature of the existing or planned uses, and the redevelopment project.

Management of radioactive waste on the contaminated site of Pargny-sur-Saulx (Marne district)

Two typical situations can be defined depending on the use to which the site is put:

- the site's uses have been established. In this case, the question posed is that of the compatibility of the surroundings (air, water, and ground) with the uses. An interpretation of the state of the surroundings (IEM) has to be carried out, comparing the measurements made in the environment with the general references valid for the population as a whole;
- the site's uses have not been established, or they can be modified (rehabilitation or change of use). In this case, a management plan has to be drawn up and implemented. Its purpose is to determine the work to be carried out in order to restore the environment's compatibility with the planned uses.

Whether management of a polluted site is implemented through interpretation of the state of the surroundings or via a management plan, the procedure involves making a diagnosis whenever contamination is suspected: this is the stage of "doubt removing". It includes a study of the documents concerned and field investigations, and its primary aim is to confirm or invalidate the presence of the suspected pollution, and then, where applicable, to determine the location, type and level of the pollution. The scope of the diagnosis must be adapted to suit the issues identified.

When the management values as to the quality of the surroundings are not sufficient to assess the compatibility between the levels of pollution and the uses noted, it is necessary to implement evaluations of radiological exposure, based on scenarios on use by the general public or by workers.

In conformity with the radiological protection principles set out in article L.1333-1 of the Public Health Code, the cost/benefit statement that is to be drawn up if the situation involves a management plan, must be aimed mainly at reducing to the lowest level reasonably possible any exposure of persons to the ionising radiation resulting from use of the site and the rehabilitation operations.

This statement constitutes a decisive stage in the procedure to define the management choices. It provides a particularly suitable framework to assess, in concert with the stakeholders, the pertinence of the assumptions adopted and check that the optimisation process has been carried out correctly. It must lead to a consensual long-term management solution.

Radium diagnosis operation

In the wake of the cleaning-up procedures already undertaken in France in the 1990s on sites that in most cases saw radium extraction and/or research activities, the French public authorities are continuing their operations to identify and rehabilitate those sites.

Indeed, radium was used in certain medical activities, and in particular for the earliest cancer treatment therapies.

Bayard plant (Seine-Maritime district)

This radionuclide was also used in craft activities such as clock- and watch-making (for its radio-luminescent properties), and making lightning conductors or cosmetics, until the 1960s. These activities may have generated traces of pollution.

On the basis of the various inventories of industrial sites that may have seen disposal and use of radium, and in particular the inventory updated by the Institute of radiological protection and nuclear safety (IRSN) in 2007 at the request of the French Nuclear safety authority, it can be seen that 134 sites have now been identified by the official state authorities concerned as having housed an activity involving radium in France. The radiological status of those sites is unknown or poorly known to the official state authorities. The sites can include housing, commercial premises, or disused industrial areas.

The radium diagnosis operation, managed by the Nuclear safety authority, consists of a radiological diagnosis carried out by the Institute for radiological protection and nuclear safety (IRSN). If traces of radium are found, precautionary measures are planned where necessary, and the health of the populations concerned is monitored. Lastly, the sites showing radium pollution are rehabilitated by Andra.

This determined, positive approach on the part of the public authorities is fully financed by public funds, so it does not involve any outlays for the occupants of the premises concerned, for the diagnosis, health monitoring or remediation.

The initial diagnosis phase, concerning the Paris region, was started at the end of September 2010.

There are also disused industrial sites on which naturally radioactive ores were processed to extract rare earth elements, which led to pollution of the sites by residues with technically-enhanced radioactivity.

This is the case, for example, of the former Orflam-Plast plant in Pargny-sur-Saulx (Marne district), which made lighter flints from an ore rich in thorium, using a process that concentrated the radioactivity in the solid residues.

The Geographical Inventory shows the sites whose radioactive pollution has been confirmed and recognised by the public authorities *(see box on page 100)*.

Contaminated site of Pargny-sur-Saulx (Marne district)

4.6

BASIAS database
http://basias.brgm.fr

France was one of the first European countries to systematically draw up inventories of the sites likely to be polluted (other than by radiological pollution); the first inventory was drawn up in 1978. The main objectives of these inventories are as follows:

- listing, on a wide-ranging, systematic basis, all the industrial sites, whether abandoned or not, likely to entail pollution of the environment;
- keeping a record of those sites;
- providing useful information for the players in the fields of urban planning, property development and protection of the environment.

The work to draw up regional legacy inventories (IHR) of industrial and service activities sites, whether they are still in use or not, was accompanied by creation of the BASIAS national database under a ministerial order issued in 1998 [VIII]. The base lists about 180,000 sites that housed an industrial or services activity in the past.

BASOL database
http://basol.ecologie.gouv.fr

The BASOL database lists the polluted sites and ground calling for action on the part of the public authorities, as a preventive or curative measure. It currently lists about 3,900 sites covered by management measures to prevent risks for the people living nearby and environmental damage.

[VIII] *Decree of 10 December 1998 on creation of a database for former industrial and service activities sites.*

In terms of classification of these sites, we can make a distinction between three categories:

- **remediated sites:** the sites that have been remediated since the previous edition; those that were shown as being remediated in 2009 are no longer covered by data sheets.

Nonetheless, a record of the sites is kept in the BASIAS database developed by the BRGM *(see box on page 102 - http://basias.brgm.fr)* ;

- **sites undergoing remediation:** the remediation work on these sites is in progress. Some of them are listed in the BASOL database *(see box on page 102 - http://basol.ecologie.gouv.fr)* ;
- **sites awaiting remediation:** these sites have been found to show pollution and they are awaiting remediation. Some of these sites are listed in the Basias database.

The Geographical Inventory lists about forty polluted sites:

- 9 sites remediated since the previous edition;
- 20 sites undergoing remediation;
- 14 sites awaiting remediation.

Some sites (Ganagobie (Alpes-de-Haute-Provence district), Arcueil (Val-de-Marne district), Aubervilliers (Seine-Saint-Denis district) etc.) set out in the 2009 edition as polluted sites, are covered by detailed data sheets in the Geographical Inventory of the 2012 edition.

Remediated sites	Sites undergoing remediation	Sites awaiting remediation
Chivres (Côte-d'Or district)	Annemasse (Haute-Savoie district)	Asnières (Hauts-de-Seine district)
Gueugnon* (Saône-et-Loire district)	Bandol (Bouches-du-Rhône district)	Charquemont (Doubs district)
Lac de Saint-Pardoux** (Haute-Vienne district)	Besançon (Doubs district)	Clichy (Publicly managed harbour) (Hauts-de-Seine district)
Marnaz (Haute-Savoie district)	Chaville (Hauts-de-Seine district)	Colombes (lumina) (Hauts-de-Seine district)
Morteau (Doubs district)	Gif-sur-Yvette (Housing estate) (Essonne district)	Colombes (Test ground) (Hauts-de-Seine district)
Oraison (Alpes-de-Haute-Provence district)	Gif-sur-Yvette (Fédéral Mogul) (Essonne district)	Compreignac (La Rode lake) (Haute-Vienne district)
Paris 3	Île-Saint-Denis (Seine-Saint-Denis district)	Huningue (Haut-Rhin district)
Pech Rouge (Gruissan)[2] (Aude district)	La Rochelle (Anse Saint-Marc) (Charente-Maritime district)	Marcheprime (Gironde district)
San-Giuliano (Haute-Corse district)	Le Perreux-sur-Marne (Val-de-Marne district)	Marseille (Bouches-du-Rhône district)
	Lyon (Quai Claude-Bernard) (Rhônes district)	Nogent-sur-Marne (YAB) (Val-de-Marne district)
	Nogent-sur-Marne (Val-de-Marne district) (Former Marie-Curie school)	Paris 5
	Orsay (CNSM - Fac. Orsay) (Essonne district)	Paris 7
	Pargny-sur-Saulx (Marne district)	Paris 8
	Paris 2	Paris 16
	Paris 5	
	Paris 17	
	Rueil-Malmaison (Disused industrial area) (Hauts-de-Seine district)	
	Saint-Maur-des-Fossés (Val-de-Marne district)	
	Saint-Nicolas-d'Aliermont (Bayard) (Seine-Maritime district)	
	Wintzenheim (Haut-Rhin district)	
9	**20**	**14**

** Site remediated by confinement.* *** Site remediated with monitoring.*

Special reports

2012 NATIONAL INVENTORY of Radioactive Materials and Waste

Waste dumped at sea

Report 1

Following work at the "Grenelle of the Sea" summit in 2009, an undertaking was made to set up better monitoring and more effective inspection of the marine environment.
With regard to radioactive waste dumped at sea, this undertaking is formalised by "Consolidating the inventory of nuclear waste dumps at sea, assessing their danger and establishing priorities to analyse the sedentary flora and fauna, and the sediments".
This chapter provides responses to the first two points. It mainly summarises the data presented in the two reference reports [I].

1. Background and history

Dumping into the sea has always been a means of managing all types of waste.

Radioactive waste is not an exception to this rule.

The simple solution of dumping this waste, i.e. depositing it on the seabed, without burying it, after conditioning for the most active waste, was in fact considered safe by the scientific community as the dilution and assumed duration of isolation provided by the marine environment was sufficient.

This practice was therefore implemented by many countries for more than four decades, from 1946.

Dumping radioactive waste into the sea in the 1960s

[I] *AIEA 1999: "Inventory of radioactive waste disposals at sea" (TECDOC 1105) and DSND: Inspection of Mururoa on 24 June 2010.*

1.1. Regulatory context

The first regulations on dumping of radioactive waste at sea were formulated by the United Nations Conference on the Law of the Sea in 1958.

These texts required all the Member States to take measures aimed at avoiding sea pollution by discharging radioactive waste and also recommending that the IAEA [1] set up safety criteria and recommendations on this subject. However, the Member States remained free to organise their offshore dumping operations.

At the start of the 1960s, the IAEA recommended that sea dumping should take place at special sites designated by a competent authority that would also control the operations.

It was in this spirit that from 1967, the Agency for Nuclear Energy of the OCDE, which only comprised European members, began to coordinate the collection of waste by European states applying for membership with a view to optimising the dumping operations.

Then, in 1972, the London Convention, recognised as the main international control of waste sea dumping prohibited from its entry into force in 1975, the dumping of highly radioactive waste and required special license to dump low-level radioactive waste.

Furthermore, the London Convention confirmed the role of the IAEA in defining the specific rules for radioactive waste sea dumping.

Despite the setting up of regulatory provisions, some of the parties at the Convention were worried by the future risks to human health and the environment, which involved the evacuation of radioactive waste at sea. A voluntary moratorium on dumping of that waste was adopted in 1983 pending a global examination of the question.

Following this examination, to which the IAEA was a major contributor, the parties signing the Convention decided in 1993 to prohibit dumping of all types of radioactive waste in the sea, specifying however that this decision was not based on certain scientific and technical grounds, but rather on moral, social and political considerations.

1.2 The different types of dumped waste

There were several types of dumped radioactive waste:

- **liquid waste**, poured directly into the sea at dedicated sites or placed in containers, but not solidified;
- **solid waste**, not conditioned, or mostly conditioned, generally in metal drums after incorporation in a cement or bitumen matrix, in compliance with IAEA recommendations.

Nuclear reactor vessels from the United States and the ex-USSR, possibly containing fuel were also included.

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1 *AEIA: International Atomic Energy Agency*

1.3
History of dumping at sea

The first dumping operation at sea was performed by the United States in 1946 in the North-East Pacific, around 80 kilometres off the coast of California, and the last (excluding the ex-USSR) took place under the management of the NEA in 1992 in the Atlantic around 550 kilometres from the European continental plate.

Between these two dates, 14 countries carried out dumping at more than 80 sites in the Pacific and Atlantic (and in the adjacent seas). The total activity of dumped waste was around 85,000 terabecquerels at the time of their dumping.

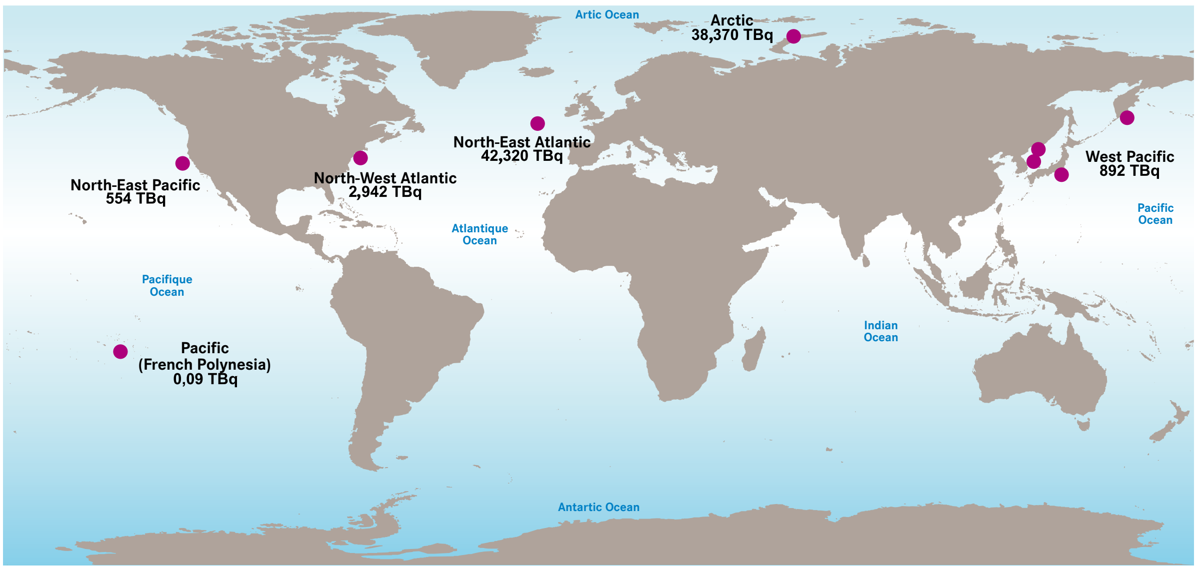
The *map below* lists the different sites used and the *table below* gives an assessment of the dumped activity for each zone concerned.

Distribution of the activity of dumped waste

	α activity (TBq)	**β/γ activity** (TBq)	**Total activity** (TBq)	**Percentage of total activity** (TBq)
North-East Atlantic	675	41,645	42,320	49.7%
North-West Atlantic	-	2,942	2,942	3.5%
Arctic	-	38,370	38,370	45.1%
North-East Pacific	0.04	554	554	0.7%
West Pacific	-	892	892	1%
Pacific (French Polynesia)	0.07	0.02	0.09	-
Total	**~ 675**	**~ 84,400**	**~ 85,100**	**100%**

99% of the total radioactivity comes from beta/gamma emitters, mainly fission and activation products such as strontium 90, caesium 137, iron 55, cobalt 58, cobalt 60, iodine 125, carbon 14 and tritium.

Worldwide radioactive waste dumping sites



2.
Dumping in the North-East Atlantic

The first dumping in the North-East Atlantic was carried out in 1949 by the United Kingdom (which had already dumped liquid waste in its own territorial waters east of Norwich in 1948) through an experimental operation carried out at a site located around 600 km to the west of Brittany.

This operation concerned 9 tonnes of conditioned waste, representing an activity of around 0.04 terabecquerels.

From that date and until 1966, the United Kingdom and also Belgium, to a lesser degree, regularly dumped waste at different sites in the Atlantic and the Channel. These two countries mainly dumped waste in the Casquets trench, located 15 km North-West of the Cap de La Hague (Manche district) *(site 2 in the table below)*.

Les immersions en Atlantique Nord-Est de 1949 à 1966

Site	Latitude	Longitude	Depth (m)	Date	Country	Tonnage (t)	Activity (TBq)
1	48°30' N	13°0' W	3,600-4,000	1949	United Kingdom	9	0.04
2	49°50' N	2°18' W	65-160	Every year from 1950 to 1963	Belgium, United Kingdom	17,274	60
3	55°20' N	11°20' W	2,700	1951	United Kingdom	33	0.2
4	55°8' N	12°10' W	2,800	1953	United Kingdom	57	0.15
5	32°37' N	14°5' W	4,000-4,200	1955	United Kingdom	1,453	1.7
6	32°42' N	19°30' W	3,600-4,100	1957-1958	United Kingdom	7,098	131
7	32°38' N	20°5' W	2,100-4,800	1961	United Kingdom	4,360	81
8	46°27' N	6°10' W	4,200-4,600	1962	United Kingdom	253	6.7
9	45°27' N	6°16' W	4,100-4,800	1963-1964	Belgium, United Kingdom	10,201	850
10	48°20' N	13°16' W	1,900-4,500	1965-1966	United Kingdom	2,803	617
TOTAL						**~ 43,500**	**~ 1,800**

Sweden, for its part, dumped 230 containers (approx. 44 cu. m) in the Baltic Sea, approximately 30 km to the South-East of the Isle of Öja, during two operations in 1959 and 1961, for a total activity of around 15 gigabecquerels (0.015 TBq).

The *table above* summarises the data collected by the IAEA on these different operations.

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1

From 1967 to 1983, date at which the moratorium on the discharging of low level radioactive waste in the sea was signed, the dumping operations were coordinated by the NEA. It concerns 3 sites, all located in deep sea trenches.

• **In 1967**, Germany, Belgium, France, the United Kingdom and the Netherlands dumped around 11,000 tonnes of waste (36,000 drums) in a site 400 km off the coast of Galicia (Spain) (site marked in violet on the *map on page 113*) at a depth of more than 4,600 meters: this waste represents a radioactivity level of the order of 300 terabecquerels.

Dumping coordinated by the NEA on the 1967 site

Country	Number of containers	Mass (t)	Activity (TBq)
Germany	480	181	0.2
Belgium	1,945	600	7
France*	31,596	9,184	220
United Kingdom	-	722	66
Netherlands	-	207	0.07
TOTAL	**34,021**	**10,894**	**293.27**

** This data for France is detailed on page 114.*

• **In 1969**, a new operation, this time grouping Belgium, France, the United Kingdom, Italy, the Netherlands, Sweden and Switzerland, dumped around 9,000 tonnes of waste corresponding to an activity of the order of 900 terabecquerels on a site 900 km to the West of Brittany, at a depth of between 4,000 and 4,600 m (Porcupine site marked in yellow on the *map on page 113*).

Dumping coordinated by the NEA on the 1969 site

Country	Number of containers	Mass (t)	Activity (TBq)
Belgium	2,222	600	18
France*	14,800	5,015	134
Italy	100	45	0.2
Netherlands	-	303	1
United Kingdom	-	1,878	665
Sweden	2,895	1,081	3.2
Switzerland	100	224	13
TOTAL	**20,117**	**9,146**	**834.4**

** This data for France is detailed page 114.*

• **From 1971 to 1982,** a single site with a surface area of 4,000 sq. km, located off the Bay of Biscay, 1,000 km from the French coast (sites marked in green on the *map on page 113*) was recommended by the NEA and used by Belgium, the United Kingdom, the Netherlands and Switzerland: 123,000 packages totalling around 35,000 terabecquerels were dumped *(see table below)*.

Dumping on the NEA site between 1971 and 1982

Country	Number of containers	Mass (t)	Activity (TBq)
Belgium	51,157	27,026	2 090
United Kingdom	-	23,788	29,050
Netherlands	> 28,428	18,652	335
Switzerland	7,370	5,097	4,407
TOTAL	**86,955**	**74,563**	**35,882**

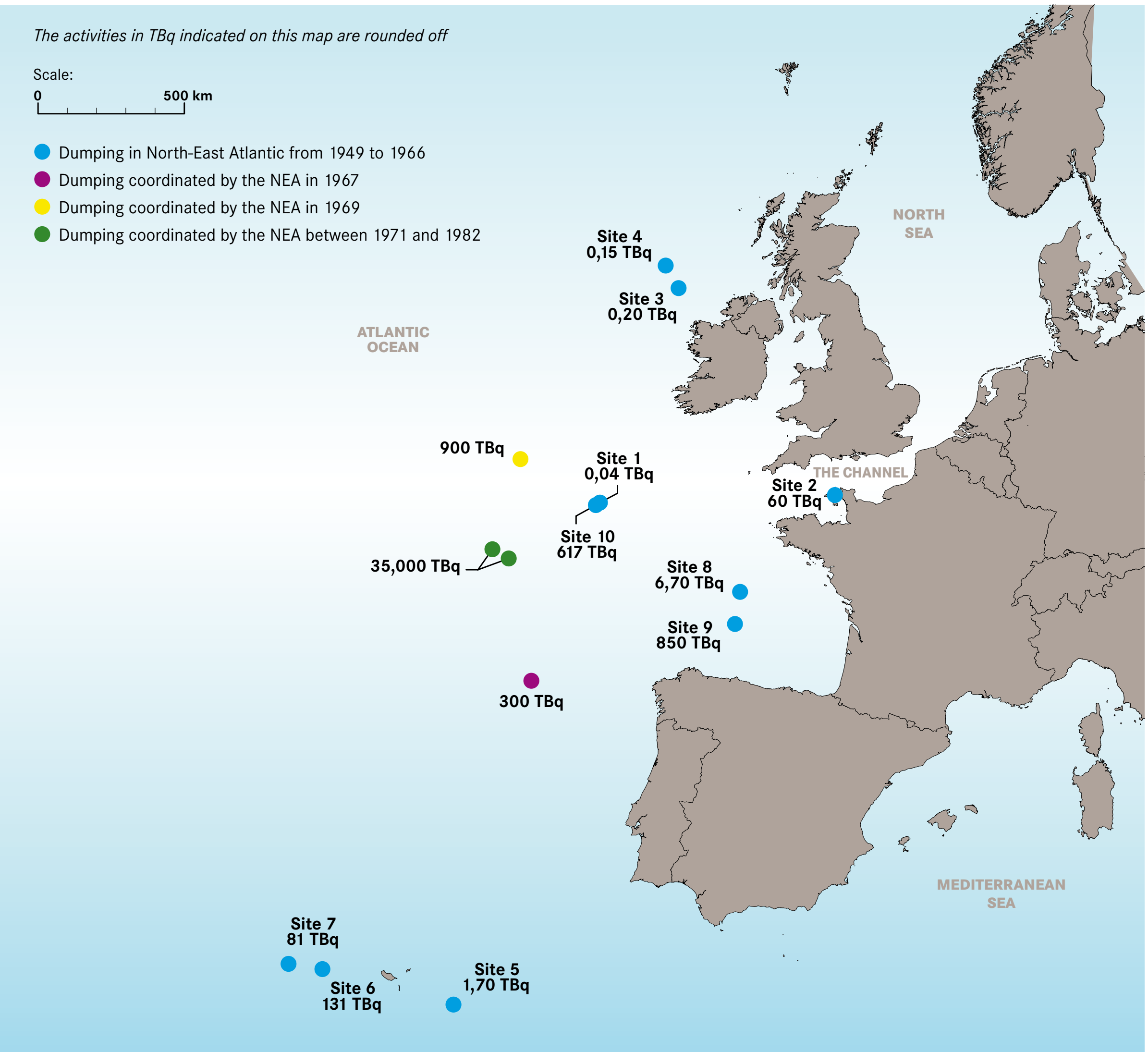
For the entire period from 1949 to 1982, the United Kingdom also carried out dumping operations in around twenty other sites in its territorial waters, mostly in the Irish Sea, with an activity of around 10 terabecquerels.

It also performed two operations in 1968 and 1970 on a site (site 10 on the *table on page 110*) in the Atlantic that had already been used in 1965 and 1966, dumping 4,838 tonnes waste with a total activity of 13,500 terabecquerels.

The *map opposite* indicates the location of the sites used in the North-East Atlantic and adjacent seas as well as the activity of the waste dumped there (at the time it was dumped).

Report
1

Sites used in the North-East Atlantic



3.
French radioactive waste dumping campaigns

As indicated above, France took part in two operations coordinated by the NEA in 1967 and 1969 in the North-East Atlantic.

It did not participate in the following campaigns coordinated by the NEA, as opening of the Centre de stockage de la Manche that was licensed in 1969.

France had also carried out dumping in the Pacific to remove waste caused by the activities related to nuclear testing performed in Polynesia.

Three sites were used, all located in French territorial waters: 2 off the Mururoa atoll, and 1 off the Hao atoll.

There was no French dumping in the Channel: only the United Kingdom and Belgium used the Casquets trench to the North-West of Cap de La Hague (Manche district).

With regard to the Mediterranean, the CEA announced in 1962 its intention to dump 6,500 drums of radioactive waste at a depth of 2,500 m, 80 km off the coast between Toulon (Var district) and Corsica, but this project was abandoned following various protests.

However, in order to check the feasibility of such operations, inactive drums were dumped in the area.

3.1.
Details of French radioactive waste dumping in the North-East Atlantic

During the dumping campaign coordinated by the NEA in 1967, France dumped 896 metal containers (347 tonnes) containing waste incorporated in a concrete matrix, corresponding to an activity of around 0.4 terabecquerels and 30,700 galvanised steel drums (8,837 tonnes) containing thick liquid effluent treatment sludge, with an activity of 220 terabecquerels.

All this waste came from the Marcoule Centre (Gard district).

During the dumping campaign coordinated by the NEA in 1969, 14,800 containers, totalling 5,015 tonnes, metal drums containing either liquid effluent treatment sludge, some incorporated in a bitumen matrix (2 201 tonnes), or waste incorporated in a cement matrix (2,814 tonnes) also coming from the Marcoule Centre (Gard district), were dumped at a depth of between 4,000 and 4,600 m at the “Porcupine” site.

The total activity of this waste was 134 terabecquerels.

3.2
Details of French radioactive waste dumping in the Pacific

Two sites were used close to Mururoa:
- the *November* site, located 4 to 8 km from the atoll;
- the *Oscar* site at a distance of 5 to 10 km *(see map)*.

These two sites enabled dumping from helicopters for *November* and from boats for *Oscar* at a depth greater than 2,000 m.

A single site, *Hotel*, was used at Hao, approximately 8 km from the atoll, to perform dumping operations from boats at a depth of 2,500 m.

76 tonnes of unconditioned radioactive waste were dumped between 1972 and 1975 on the *November* site, with a total radioactivity of eight gigabecquerels (0.008 TBq).

At *Oscar*, 2,580 tonnes of radioactive waste, unconditioned or conditioned in concrete containers, were dumped between 1974 and 1982, with a total activity of approximately 60 gigabecquerels (0.06 TBq).

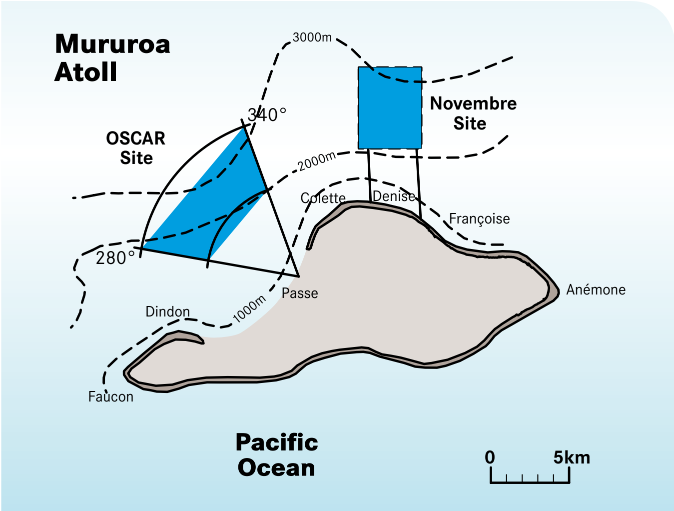
The activity of this waste came mainly from alpha emitters, in particular plutonium.

Finally, 310 tonnes of radioactive waste conditioned in concrete drums and 222 tonnes of unconditioned radioactive waste were dumped at the *Hotel* site between 1967 and 1975: the activity of this waste is due to beta-gamma emitters and is approximately 15 gigabecquerels (0.015 TBq).

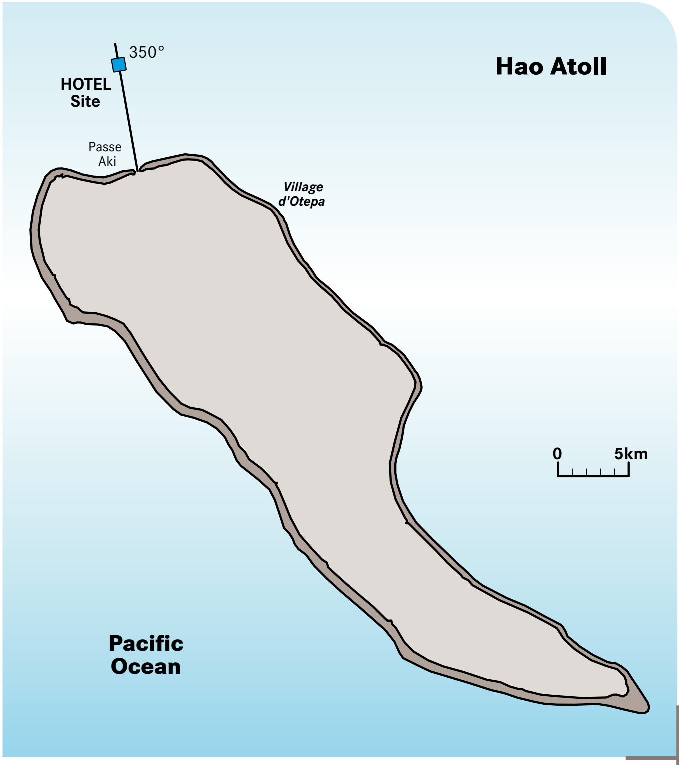
It should be noted that these sites were also used, mainly after 1982, for dumping non-radioactive waste.

These three sites are described in greater detail in the Geographical Inventory.

Sites used in French Polynesia



Mururoa site



Hao site

4.
Monitoring dumping sites

Until 1977, in compliance with the provisions of the United Nations Conference on the 1958 Law of the Seas, Member States were free to organise and supervise their own radioactive waste dumping on condition that the recommendations issued by the IAEA, in particular with regard to the choice of dumping site, control of operations and assessment of the radiological impact were observed, and that the IAEA was kept informed of the operational details.

Monitoring of the sites was therefore under the sole control of the Member State concerned, as defined by the London Convention.

In 1977, the majority of NEA members, in particular those having participated in the coordinated dumping operations but also those who opposed these practices, wished to increase cooperation with a view to adding effective international monitoring to the national control.

This desire was at the origin of the OECD Council decision to set up a “multi-lateral consultation and monitoring mechanism for the dumping of radioactive waste in the sea”, which replaced the *ad hoc* and voluntary arrangements in place until then. This decision obliged member countries of the NEA to be subject to the directives and monitoring performed by the NEA.

4.1.
Monitoring of the sites used, mainly under NEA coordination

In 1977, there was only one site still used by the NEA for dumping (sites marked in green on the *map on page 113*).

The OECD Council decision also obliged the NEA to assess at least every 5 years whether that site was still appropriate.

A research programme christened CRESP [II] was then set up in 1980 to provide reliable and complete scientific data for assessment of the site.

Essentially concerned with the radiological consequences of dumping, and based on the study of processes controlling the transfer of radionuclides in the marine environment to establish safety assessments, the international programme integrated a lot of data on oceanography, water geochemistry, biology, etc., collected by all the research ships that operated on or in the area of the last dumping site used from 1971 to 1982 but also on the two sites used by France in 1967 and 1969 (sites marked in yellow and pink on the *map on page 113*).

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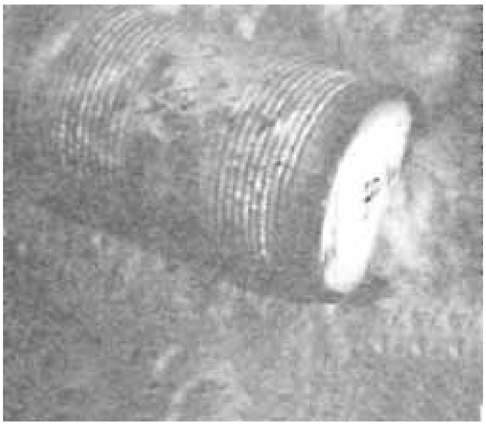
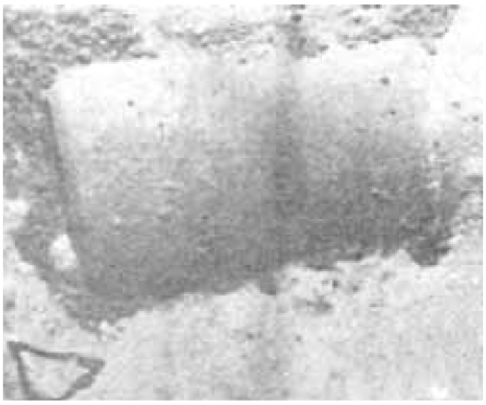
[II] *NEA 1996: Coordinated Research and Environmental Surveillance Programme Related to Sea Disposal of Radioactive Waste.*

Photographs taken in 1984 of the containers dumped in 1979



Metal container



Concrete container

The results from analysis of samples collected showed no significant increase in the concentration of radionuclides present in the dumped waste.

The radioactivity observed in the waste dumping zone is indistinguishable from the fluctuations of the natural radioactivity on the ocean floor.

Taking into account the low levels of exposure and irradiation found, the need for continued monitoring on the NEA site after the total prohibition of dumping radioactive waste was not retained and the CRESP programme was therefore ended in 1995.

In parallel to these monitoring programmes based on the interpretation of different measurements, a direct photographic reconnaissance campaign of the NEA site was organised by IFREMER, in collaboration with the CEA in June 1984 [III].

An unmanned submersible surveyed a linear distance of 61 km at an average altitude of 3.6 m from the bottom, taking 15,890 photographs at a rate of one photograph every 5 seconds. Six containers were photographed (from a total of 123,000 dumped in this zone). Five were metal containers (like the majority of the conditioned waste dumped on this site) and the sixth was concrete.

In 1984, these six containers seemed to be intact despite a few deformations. The impact of these two types of containers when they arrived at the bottom is different and seems to depend on the density of the container. The five metal containers were slightly embedded in the sediment; the cement container was more deeply embedded in the centre of a large crater.

The covering of some metal containers seemed corroded. Two of the containers were identified as belonging to those dumped in 1979.

[III] *Report from the Academy of Sciences t. 301, series III, No. 10, year 1985: "Photographic reconnaissance of containers in place in the low level radioactivity waste dumping zone in the North-East Atlantic" by Myriam Sibuet, Dominique Calmet and Gérard Auffret.*

Finally, at the start of the 2000s, Greenpeace carried out an exploration of the Casquet trench sea bed, used by the United Kingdom and Belgium, at a depth of up to one hundred metres. After locating the radioactive waste drums, a remote controlled vehicle equipped with cameras descended to the bottom for a more detailed inspection that found that a number of drums had degraded.

The countries involved in the past with these dumping operations, including those within the framework of the operations coordinated by the NEA, remain responsible for these operations. Any new measurement or photographic campaign therefore remains at the initiative of each country concerned.

4.2 Monitoring of the Mururoa and Hao atolls

When French nuclear testing in the Pacific finally stopped in 1996, France asked the IAEA to carry out a radiological assessment of the Mururoa and Fangataufa experimental sites and the areas close to those sites.

This assessment provided a reference situation for the level of activity in the environment of the two atolls where the experiments took place. Even though the IAEA experts concluded that it was unnecessary to continue radiological monitoring of the atolls, it was decided to maintain a monitoring program to detect any release of radionuclides from cavities and sediment in the lagoons.

This monitoring concerns the environment of the two atolls and has two parts:

- continuous monitoring of atmospheric aerosols and the integrated dose;
- an annual sampling campaign, the Turbo mission, carried out each year from March to June.

Samples of different species of flora and fauna, both land and marine, as well as underground water in the atoll, are collected to measure the radioactivity. All the samples are the subject of radiological research for gamma emitting radionuclides and a selection of them are measured for tritium, strontium 90 and plutonium isotopes.

The radionuclides measured between Mururoa and Fangataufa are present at very low levels, often close to the detection levels of the radioactivity measuring devices.

More especially with regard to the Hao dumping zone, radiological sampling of water at various depths at the dumping site was performed in 2007. No increase in radioactivity was found in relation to the reference oceanic radioactivity.

Management of spent radioactive sources

Report 2

1.
Spent radioactive sources considered as waste

Radioactive sources may be of two types, sealed and unsealed *(see box).*

The use of radioactive sources is regulated by the French Public Health Code, which requires, in particular (article L. 1333-7) that the supplier of sealed sources must take responsibility for them when they cease to be used.

Spent sealed sources pending a final solution are stored in appropriate facilities (supplier obligation to provide appropriate facilities). Spent sealed sources of foreign origin marketed in France are returned abroad by the supplier within the framework of a contractual undertaking between the foreign manufacturer and the supplier in France.

For this reason, only the sealed sources that are not reused by their manufacturer are considered as waste and included in this inventory.

By their nature, unsealed sources cannot be recovered. Their use produces solid waste and radioactive effluent, which is managed according the usual solutions and are listed in the *National Inventory* as such.

Definition of radioactive sources

Appendix 13-7 of the French Public Health Code defines a source as a "device, radioactive substance or installation emitting ionising radiation or radioactive substances".

Unsealed radioactive sources: "sources for which the presentation and normal use conditions do not allow any dispersal of radioactive substances to be prevented". They therefore present both an irradiation risk and a risk of contamination by contact, ingestion or inhalation. These sources may be liquid or solid.

Sealed radioactive sources: "a source for which the structure or conditioning, in normal use, prevents any dispersal of radioactive material into the surrounding environment". The majority of sealed sources are solid.

Article R. 1333-52 of the Public Health Code

"A sealed radioactive source is considered as obsolete ten years at the latest after the first date, registered on the supply form, or by default, after the date it is first marketed unless an extension is granted by the competent authority.

All users of sealed radioactive sources are required to return obsolete sources or sources no longer used to the supplier. However, by special dispensation, this obligation is not applicable if the characteristics of the source allow for its decay at the site where it has been used. Deteriorated sources are returned under the same conditions without special dispensation.

The supplier of sealed radioactive sources, products or devices containing them, is under obligation to recover, without any conditions and on simple request, any sealed source that they distributed, especially when this source is obsolete or when its holder no longer has use for it. When the source is used in a device or product, the supplier is also required to recover it in its entirety if the holder so requests.

The supplier may either remove the recovered sources or have them removed to an installation licensed for this purpose or return them to its supplier or manufacturer.

The supplier must declare all sealed sources, products or devices containing them that have not been returned to the supplier within the required time delay, to the Nuclear safety authority (ASN) and the Radiological protection and nuclear safety Institute (IRSN)."

2. Waste produced by the use of unsealed sources

2.1 Use of unsealed sources

Research sector

Unsealed sources are used within the research sector for marking molecules or as a radioactive tracer.

The most commonly used radionuclides are:

- very short-lived: phosphorus-32 and 33, sulphur-35, chromium-51, iodine-125;
- short-lived: tritium;
- long-lived: carbon-14.

With regard to cellular and molecular biology, hydro-geology and other fields of study of physical and chemical mechanisms, they are used to mark the molecules into which they are incorporated to monitor a dynamic mechanism.

Medical sector

Unsealed sources are widely used in the medical sector to establish diagnoses and for certain treatments.

Diagnosis applications *in vitro*

Radiography analyses, carried out in laboratories, which are usually linked to nuclear medicine departments, are used to make bioassays on samples.

They have become 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, amongst others.

Many laboratories also carry out radio-immune assays. These are very precise techniques to assay biological substances such as enzymes, hormones or other molecules in the blood, urine or saliva, for example.

Diagnosis applications *in vivo*

Various diagnosis applications using medical imaging are based directly on the properties of radioactivity. These techniques are used to locate and examine body organs (anatomical medical imaging) or to visualise how they are working (functional medical imaging).

In isotope scanning, when a radiopharmaceutical product 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 *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 opposite)*.

Tomography techniques draw on the properties of X-rays or gamma rays.

Developments are taking place to extend fluorine-18 positron emission tomography applications to the fields of neurology, cardiology and oncology.

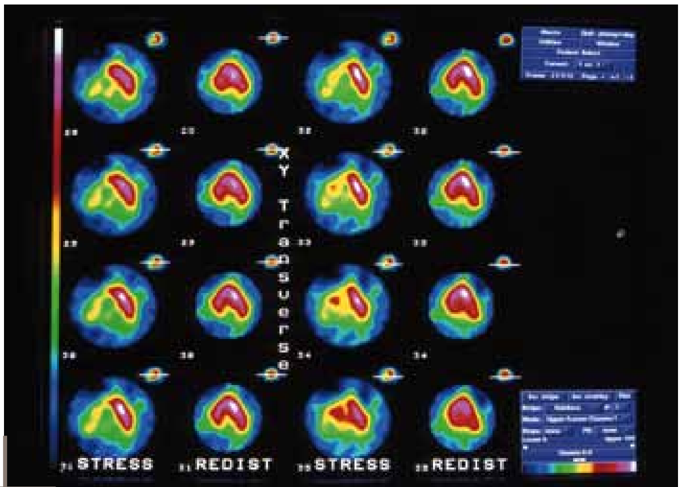
Therapeutic applications

Therapeutic applications of unsealed sources are based on the selective destruction of cells *via* the use of a radiopharmaceutical product in liquid or capsule form.

The product contains a radionuclide, which is permanently and specifically attached to the organ or tissue to irradiate.

The objective of this technique, called metabolic radiotherapy, is the destruction of cancerous cells and the maximum preservation of healthy cells.

Certain techniques demand specific radionuclides specifically conditioned in particular ways (iodine-131 in capsules, iridium-192 in wires).



Cardiac isotope scanning

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Main radionuclides used in the medical sector (classified in ascending order according to mass number together with radioactive half-life)

Radio-nuclide	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	Sulfure-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

Radio-nuclide	Name	Radioactive half-life
^{99}Mo	Molybdenum-99	2.75 days
$^{99(m)}Tc$	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 ans
^{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}Ir	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 database (OECD-NEA).

2.2
Management of the waste produced by the use of unsealed sources

Solid waste

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).

This waste is collected in specific containers to prevent any radioactive risk.

Very short-lived waste is stored separately *in-situ* pending the decay of its radioactivity, and then removed.

It is then removed by conventional hospital waste disposal firms once the final measurements have been made of any residual radioactivity.

Waste that cannot be handled in this way is sent to an Andra repository.

Liquid waste

Aqueous liquid waste coming from laboratories and hospitals is collected in tanks and stored on-site. If the waste has a half-life of less than 100 days, it remains on site to allow for its radioactivity to decay. If this effluent contains radionuclides with a longer half-life, it is collected, treated by incineration at CENTRACO (Gard district), and then dispoed of by Andra.

These activities also lead to the production of contaminated solid waste (gloves, tubes, glassware, etc.). This waste is managed like other waste products produced from the use of unsealed sources.

Handling in the laboratory

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3.
Waste produced by the use of sealed sources

In this case, the waste is the sources themselves. These may be very different in form and activity according to the sector in which they are used.

The first sealed sources appeared in the 1920s, with radium in radioactive lightning conductors (1932) and radium needles for medical use.

Since the 1950s, the sealed sources use artificial radionuclides.

Exemption threshold (extract from appendix 13-8 of the Public Health Code)

"The nuclear activity in a) and b) of 1° of article R. 1333-27 may be exempted from license as long as the quantity or concentration of the activity of the radionuclides concerned does not exceed the values indicated in the tables in the appendix."

These nuclear activities are:

• manufacture of products or devices containing them;

• distribution of radionuclides, products or devices containing them;

• use of apparatus emitting X-rays or radioactive sources and use of accelerators other than electron microscopes.

Collection of lightning conductors

These sources are used in various sectors:

• sources for industrial applications, teaching and research: research and industrial irradiation, non-destructive testing, density, level, thickness and humidity gauges, etc., elimination of static electricity, analysis, calibration, chromatography and detection by capture of electrons, neutron generators, analysis by X fluorescence, etc.;

• sources for medical ends: gamma beam therapy, brachytherapy (or internal radiotherapy), pacemakers, anatomical marking, bone density measurement, irradiation of blood bags, etc.

Other types of sources are widely used and are not the subject of individual monitoring as the natural radionuclides or radionuclide activity is lower than the exemption thresholds defined in 13-8 of the Public Health Code.

The following paragraphs describe the different types of sources likely to become waste.

3.1 Sealed sources for industrial applications

The use of artificial radionuclides in the form of sealed sources associated to apparatus is common in the industrial sector.

Non-destructive testing and analysis of materials

These include, for example:

• inspection of welds by gamma radiography (iridium-192 or cobalt-60 sources);

• detection of toxic products such as lead in paint (cadmium-109 or cobalt-5);

• detection and assay of molecules in pesticides, explosives or drugs by gas chromatography (nickel-63 or tritium sources).

Measurement systems

Density, level or thickness gauges, made up of an emitter unit (krypton-85, caesium-137, americium-241, cobalt-60 or promethium-147) and a radiation detection unit, are used on paper, fabric, plastic or thin metal. These apparatuses are used in the paper or tobacco industries, for example.

Control and monitoring of nuclear power operations

These operations require the use of sealed sources, mainly in:

• fixed radiation protection installations of the reactor control system by the use of caesium-137, strontium-90, radium-226 and americium-241 sources.

Their activity levels are less than 3.7 mega-becquerels;

• power measurement systems (boron meter, control of instrumentation channels) by the use of americium-beryllium sources.

Their activities are less than 150 gigabecquerels (0.15 TBq).

Industrial irradiation

The ionising radiation emitted by radioactive sources is used for its effects on living materials, mainly for:

• sterilisation of medical materials and pharmaceutical products;

• preservation of certain food products (destruction of micro-organisms and parasites);

• inhibition of germination (potatoes, for example) by low dose irradiation;

• removal of parasites from cereals and fruits;

• slowing down the physiological decomposition process by low dose irradiation;

• industrial sterilisation of meats, spices and prepared foods by high dose irradiation.

3.2
Sealed sources for medical use

In medicine, radioactive sources are mainly used in two main sectors:

- treatment of blood:

sealed radioactive sources are used to irradiate blood before transfusion. This treatment inhibits proliferation of lymphocytes and this reduces problems with the patient's immune system;

- radiotherapy:

there are four radiotherapy techniques: **external radiotherapy, metabolic radiotherapy, radio surgery and brachytherapy (or internal radiotherapy).**
External radiotherapy or gamma beam therapy is based on the gamma radiation from cobalt-60 sources.

The use of these sources is gradually being withdrawn in favour of electron linear accelerators producing x-ray beams and high-energy electron beams.

Sealed source – cobalt-60 gammatherapy

Sealed sources used in radiotherapy have high activity levels, with radionuclides that may have half-lives of several years.

Radio surgery is close to external radiotherapy. It uses ultra-focused beams coming from a linear accelerator of specialised irradiator (multiple cobalt-60 sources). This technique is nevertheless not widely used.

In brachytherapy (or internal radiotherapy), the sealed source is placed inside the patient for a limited duration or permanently, depending on the case, in contact or in the immediate vicinity of the area to be treated.

The main radionuclides used (iridium-192, iodine-125, caesium-137, cobalt-60, palladium-103 and ruthenium-103) have permanently replaced the radium historically used in the first half of the 20th century in the form of needles and tubes *(see box page 128)*. Their radioactive half-lives extend from 17 days for palladium-103 to 31 years for caesium-137.

Box of radium needles

Items made of radium

At the beginning of the 20th century, therapeutic use of radium to destroy diseased tissue was put forward. In view of the spectacular results, radium became very popular in the 1920-1930s.

At this time, a large quantity of pharmaceutical products, manufactured and others (powders, ointments, wools, animal food, spark plugs, fountains, etc.) were sold in France.

At the end of the 1950s, their manufacturing, production and sale were prohibited due to the danger of their radioactivity. Most of these products, by their nature, were consumed. Others still contain radium.

Items containing radium for medical use – ORUM – (needles and applicators used in treatment of tumours) form the majority of potentially recoverable products.

The Central Service for protection against ionising radiation (SCPRI) in 1985, then the Office for protection against ionising radiation (OPRI) with Andra in 1999 and 2000, collected more than 3,400 ORUM items from radiology centres, clinics, oncology centres and mainly from individuals, corresponding to around 1.3 terabecquerels of radium. Close to 2,800 items containing radium for medical use were collected during the first campaign, and 500 during the second, plus several more that have been added since. Other items (tubes of ointment, radium fountains, etc) are now progressively collected and stored on CEA sites pending the opening of the Andra repository in October 2012.

Radium lightning rod

3.3
Other types of sealed sources

Lightning conductors

At the start of the 20th century, scientists had the idea of adding sealed radioactive sources to the heads of lightning conductors to reinforce the natural ionisation of the air. In fact, at that time the scientific community thought that ionising the air around a lightning rod made it more effective against lightning. Ionising lightning conductors were manufactured in France from 1932 to 1986 by the companies HELITA then Duval Messien, Franklin France and Indelec. They were sold in large numbers abroad. As their efficiency was unproven, their manufacture was prohibited by Order on 11 October 1983, applicable from 1 January 1987.

The total number of lightning conductors installed in France is estimated to be approx. 50,000, of which 30,000 are equipped with radium-226 sealed sources (or both radium-226 and americium-241 – mixed lighting conductors) and 20,000 with sealed americium-241 sources *(see box on page 129)*.

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2

The activity of a radium-226 lightning rod head is around 50 mega-becquerels, and that of an americium-241 lightning rod head is around 20 mega-becquerels.

The radioactive substances are presented in the form of generally small-sized plates, sheets or porcelain balls.

Lightning conductors

An estimated 50,000 radioactive lightning conductors 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 these firms on request, to anyone owning a lightning rod. It should be noted that collecting and storing radioactive lightning conductors is subject to licensing by the Nuclear safety authority (ASN).

Andra collects around 500 to 600 lightning rod heads per year. The radium-226 lightning conductors are sent to the CEA centre at Cadarache (Bouches-du-Rhône district) to be compacted and conditioned in 870 litre drums and then stored pending final disposal.

Americium-241 lightning conductors are conditioned in 200 litre drums then stored on a specific platform at the SOCATRI site at Bollène (Var district), which has been licensed for use by Andra since 2003. The final conditioning of these lightning conductors and their disposal solutions are being studied.

Smoke detectors

The most widely used model of smoke detector in France is the ionic detector. It uses the radioactive properties of small sealed sources.

The source ionises the air contained in the device. When smoke enters it, electrical conductivity drops; this sets off the alarm. The number of smoke detectors with sealed radioactive sources sold in France is estimated at between 6 and 8 million. In general, these detectors contain an americium-241 source with an activity of around 30 kilo-becquerels. The unit activity of some sources has recently been reduced to around 10 kilo-becquerels, or less. Some detectors use radium-226 or plutonium-238. These detectors are prohibited for domestic use and are most often employed in office buildings and public places.

The Order of 4 April 2002 (Public Health Code) restricted commissioning of equipment containing radioactive materials. Provisions were therefore implemented for progressive replacement of ionic detectors by optical detectors.

Smoke detectors

Radio-luminescent items containing radium-226 and tritium

Paint containing radium was used until the 1960s. Radio-luminescent paint was made of zinc sulphide mixed with linseed oil and radium, and was used for applications related to night vision in the watch and clock-making industry (alarm clocks, clocks) and the armed forces (compasses, signalling, aiming devices, dials, etc.).

Radium was replaced by tritium, a radionuclide with a shorter half-life and therefore less toxic, and which itself has now mostly been replaced by non-radioactive luminescent paint when the characteristics so permit.

Radio luminescent alarm clock

Overvoltage arresters and electronic tubes

In the years between 1960 and 1970, lightning conductors or overvoltage arresters and electronic tubes (predecessors of transistors) containing radionuclides in gas form (such as krypton-85) or paint form (tritium or radium-226 for example) were used to protect electrical installations from overvoltages.

These sources were produced in large quantities; in some years, production reached over one million items. These were mainly used to protect electronic equipment (radar, for example) and telephone networks.

Today, a few nickel-63 electronic tubes are still produced for radar protection.

Other historical sealed sources

All the sealed sources described above were produced on a large scale, in thousands or millions.

Other sealed sources with less common characteristics were produced in small quantities throughout the 20th century. Examples:

- strontium-90 isotope generator sources for electrical production, with very high activity levels, of which around 10 were produced;
- cardiac pacemaker sources or “thermopiles” containing plutonium-238 manufactured between 1968 and 1976 by the CEA, around 3,000 items produced

Main French manufacturers of sealed radioactive sources

The atomic energy and renewable resources commission (CEA) - historical manufacturer

The CEA was the main manufacturer of sealed sources in France.

This production was initiated by the Department of Radioelements and progressively diversified to other departments of the CEA, mainly the Transuranic Department (especially neutron sources) and the Ionising Radiation Applications and Metrology Department (DAMRI).

DAMRI comprised several laboratories including the Ionising Radiation Measurement Laboratory (LMRI), which mainly manufactured and sold reference sources, and the Radiation Applications Service (SAR), which was and remains a designer and distributor of industrial gauges.

In 1985, the CEA decided to abandon some of these activities. CIS bio international, a subsidiary of CEA, took over the manufacture and sale of industrial sources and the LMRI retained the manufacture of reference sources.

The CEA gradually reduced its industrial activities.

In 1992, the activities of the Transuranic Department were transferred to the Alpha workshop and laboratories for analysis, transuranics and retreatment studies (ATALANTE) on the CEA site at Marcoule (Gard district).

In 1999, the Radioactivity reference standard laboratory (LEA) of Cerca (Company for the study and production of atomic fuels - AREVA group) purchased the LMRI procedures and catalogue.

CIS bio international

CIS bio international, now a member of the Belgian IBA group (Ion Beam Application), has the POSEIDON irradiator, which contains irradiation devices for biomedical and industrial products.

In 2000, CIS bio international stopped its production of sealed sources to concentrate on manufacture of unsealed medical sources or radiopharmaceutical products containing short half-life radionuclides. The firm has refocused on radionuclide substitutes for diagnosis and therapeutic applications and for the pharmaceutical industry.

CIS bio international stores spent sealed sources at the Saclay site (Essonne district), for itself and on behalf of the CEA. In 2009, the CEA and CIS bio international set up High-level sources Public interest group (GIP sources HA) with the main purpose of collection and elimination, in less than 10 years, of cobalt-60 and caesium-137 sources distributed by the CEA or CIS bio international.

The Radioactivity Reference Sources Laboratory (LEA)

Installed on the Pierrelatte site (Drôme district), this company is the only producer of significant quantities of sealed sources in France.

Belonging to the AREVA group, the LEA manufactures approximately 400 sources per year, of all types. The base products required for the production of reference sources are highly active solutions, solids or gas products produced in reactors or particle accelerators.

Other manufacturers and suppliers

Other than these manufacturers, there are several suppliers of sources, some of whom manufacture equipment containing sources or have the capacity to produce or recover sources outside France:

- maintenance, source conformity inspection, and material decontamination companies (CETIC, CERAP, Intercontrôle, Saphymo, SGS Multilab, Elta, etc.);
- Thalès, which continues to manufacture electronic tubes;
- transit areas for foreign manufactured sources (Healthcare-ex. Amersham, for example)

4.
Inventory of spent radioactive sources considered as waste

Waste coming from use of unsealed sources is not differentiated from the volumes of waste of different categories.

On the other hand, spent sealed sources considered as waste are the subject of specific listings consistent with the available data in the IRSN database as part of the inventory of sealed sources.

At 31 December 2010, approximately 3,500,000 spent sealed sources were listed.

The majority of these sources correspond to ionic smoke detector sources (74%). 23% of the sources listed are from decommissioned armed forces equipment, including radio-luminescent items containing radium and tritium (compasses, aiming devices, etc.).

The other 3% corresponds to unused sealed sources, recovered and stored by the main source manufacturers and suppliers.

Packages of spent sealed sources from the past such as AEC "source blocks" stored at Cadarache (Bouches-du-Rhône district) represent 125 cu. m conditioned equivalent.

The volume of lightning rod packages is 120 cu. m including 39 cu. m of lightning conductors containing radium and 81 cu. m containing americium, stored at SOCATRI (Gard district). 1 cu. m of cobalt 60 sources is disposed of at the LILW-SL disposal facility in the Aube district.

There is no conditioned equivalent volume associated to the other types of spent sealed sources considered as waste.

In fact, their conditioning for disposal is being studied and numerous exchanges between Andra and the holders of the spent sealed sources have taken place. The CEA has made an initial estimate of the sealed source package flow.

All these exchanges take place within the working framework defined in the National Plan for the management of radioactive waste and materials (PNGMDR).

Spent sealed source container

Monitoring radioactive sources

Before 2002, use of natural radionuclides was only covered by the French Labour Code, whereas use of artificial radionuclides had additionally been regulated by the French Public Health Code since the start of the 1950s via the Inter-Ministry Commission for Artificial Radio-elements (CIREA).

In fact, license encompassed the practices involving artificial radionuclides (manufacture, sale, distribution, possession and use) and over the years, a use limit (10 years) was set. Since then, numerous special use conditions have been introduced. This is the case for sources not returned after 10 years (implanted medical sources, sources in reactors, etc.) and sources not requiring license (activities lower than the exemption thresholds defined in appendix 13-8 of the Public Health Code, possession without license on condition of observing special requirements, etc.).

Furthermore, sources containing natural radionuclides (radium, for example) did not require license as their use had not been covered by the Public Health Code.

Since 2002, the licenses required by the Public Health Code have been delivered by the competent authorities: prefectures, the Nuclear safety authority for activities and installations involving defence (ASND), etc.

The Institute of radiological protection and nuclear safety (IRSN) records movement of these sources in France and keeps an up-to-date inventory.

This National Inventory centralises the licenses delivered by the different competent authorities for radioactive sources and the movement of sources on French territory (acquisition, transfer, export, import, recycling, replacement, etc.).

It also enables the source to be identified, with its radionuclide, its level of activity at a given date, the date its use was licensed, the name of the manufacturer, supplier and user organisation, and the technique in which it participates.

Therefore, the number and use of each source is known at all times.

For more information: www.irsn.fr

CEA spent source management forecasts

The CEA has made an initial estimate of the number and volume of source packages that it will send to disposal (in addition to the “source blocks”, i.e. 41 packages of 3 cu. m intended for Cigéo geological disposal). This estimate (in order of magnitude) takes into account the sources manufactured and distributed by the CEA or CIS bio international, and which have been or will be collected. It should be remembered that the CEA and CIS bio international were by far the largest producers of sealed sources in France in the past. It concerns only the sources that will be managed as radioactive waste, and not those that will be managed as radioactive materials and recycled in the source industry.

- **Surface disposal of LILW waste:**

10,000 sources have been conditioned in 45 cement packages of 5 cu. m (the vast majority of these sources are cobalt-60 sources; the others are sources with a half-life lower than cobalt-60, and a few sources of europium-152/154 and barium-133).

- **Cigéo geological disposal:**

- ILW-LL waste: 400,000 sources have been conditioned in 40 cement packages of around 0.9 cu. m. This type of package can receive all types of sources, with specific pre-conditioning per source family; the most numerous sources are the smoke detector americium 241 sources.

- HLW waste: 7,000 sources have been conditioned in 6 welded metal packages of around 0.2 cu. m. This type of package will receive the stock of plutonium-238 sources recovered from cardiac pacemakers, and the very high activity caesium-137 and strontium-90 sources.

These estimates are still likely to change and represent, with the conditioning assumptions described above, a volume of 200 to 250 cu. m surface disposal and 150 to 200 cu. m deep disposal (including only about 1 cu. m of HLW, and including 125 cu. m of packages that have already been constituted in the past).

Naturally radioactive waste (technically-enhanced or not (NORM - TENORM))

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3

Waste with technically-enhanced natural radioactivity (TENORM) is generated by transformation of raw materials naturally containing radionuclides but which are not used for their radioactive properties. These radionuclides may be found concentrated in materials or waste coming from transformation procedures and require special management.

1. Management of TENORM waste and regulations

Certain industries not involved in nuclear power use manufacturing procedures that sometimes lead to concentrating natural radioactivity. This waste may be classified into four categories according to its history, its level of activity and the half-life of the radionuclides it contains:

- **LLW-LL type TENORM waste:** this waste is radium-bearing (radium contaminated) and it will be disposed of in an appropriate repository, currently being studied *(see special report 4)*. The sites storing this type of waste are the subject of Geographical data sheets;
- **VLLW type TENORM waste:** this waste is sent to the VLLW disposal facility in the Aube district. The waste that is stored on site awaiting transfer to this facility is also the subject of Geographical data sheets;
- **ENR waste disposed of *in situ*:** this waste was disposed of, at the time of its production, in repositories not falling under Andra's responsibility. Some VLLW waste was used as backfill (for example at the La Rochelle site - Charente-Maritime district) or disposed of as internal landfill (for example, phosphogypsum heaps). These past disposal solutions are the subject of data sheets in the part dedicated to legacy sites in the Geographical Inventory;
- **waste sent to conventional waste disposal centres:** the regulations provide the possibility of disposing of TENORM waste in conventional disposal installations (called as well waste disposal installation or ISD). They must be the subject of an impact study before this is permitted [I].

Certain recycled, technically-enhanced naturally radioactive residues from industrial processes are not declared in the *National Inventory* but are presented in this report: this is the case with coal ash.

RHODIA Plant (Charente-Maritime district) – LLW-LL waste

[I] *Circular of 25 July 2006 BPSPR/2006-217/HA.*

Until 2005, there were no specific regulations for this type of waste. In 2005, an Order relating to "professional activities implementing raw materials naturally containing radionuclides, not used for their radioactive properties" was issued. This Order stipulated that all operators of installations listed in appendix 1 of the Order had to supply the Nuclear safety authority with a study intended to estimate the dose received by the population due to the installation [II].

The circular of 25 July 2006 [I] provided a strict framework for the management of "this waste containing radioactive substances for which the activity or concentration cannot be ignored from a radiological protection viewpoint".

In fact, the acceptance of TENORM waste in a conventional disposal centre depends on a prefectural license, granted following its application filed by the disposal centre operator.

The disposal centre operator must accompany any request to the prefect concerned with a specific impact study of the radiological risk.

This type of study is codified; it must be produced in compliance with a technical guide published by the Minister for the Environment and the IRSN in 2006 [III].

RHODIA Plant – radium contaminated waste

The impact study must demonstrate that the impact of storing such waste may be ignored from a radiological protection viewpoint, both for the operating personnel and the neighbouring population, even over the long term. The circular also specifies that this method of management is reserved for limited batches of well-identified and characterised waste. Periodic statements comprising the condition of any TENORM waste must also be presented to the local information and oversight committees (CLIS) of the disposal centres to correctly inform the neighbouring public. The circular of June 2009 reinforces the HCTISN recommendations, in particular on the monitoring provisions and information on the disposal sites containing TENORM waste [IV].

[I] *Circular of 25 July 2006 BPSPR/2006-217/HA.*

[II] *Order of 25 May 2005 (JO No.126 of 1 June 2005) related to professional activities implementing raw materials naturally containing radionuclides, not used for their radioactive properties.*

[III] *Guidelines for accepting naturally radioactive waste in installations classified for elimination DEI/SARG/2006-009.*

[IV] *Circular of 18 June 2009 relating to implementation of recommendations from the High Committee for transparency and information on nuclear safety.*

2.
Activity sectors and waste products

It is hard to list all the industries likely to produce this type of naturally occurring radioactive waste. The type of industries currently likely to produce this type of naturally radioactive waste was established and is divided into two parts: the industrial sectors listed in appendix 1 of the Order of 25 May 2005, and the sectors not concerned by that Order.

The list is based on feedback concerning known industrial practices, now and in the past, and on two reports published by the ASN in 2009 [V] based on studies performed by the Robin des Bois association [VI].

Additionally, the Minister in Charge of the Environment monitors the national statement for the management of this waste *(see box below)*.

Added effective doses compiled by the IRSN (period 2005-2010)

Every year, the IRSN publishes a report providing a statement of professional exposure to ionising radiation in France.

The 2011 report [VII] in particular reports on the added effective doses between 2005 and 2010.

The table below shows that the added effective doses are lower than 1 mSv/year except in the sectors processing minerals and certain metals, manufacturing of refractory ceramics and glassware and production of zircon. However, these exposures remain below 5 mSv/year.

In the case of production or use of components containing thorium, the annual dose is higher [VII].

Category	Number of workstations	Range of added effective doses	Percentage of doses above 1 mSv/year
Combustion of coal in thermal power plants	32	< 1 µSv/year to 0,4 mSv/year	0%
Treatment of tin, aluminium, copper, titanium, niobium, bismuth and thorium ores	42	50 µSv/year to 4 mSv/year	30%
Production of refractory ceramics and glassmaking, foundry, steel and metalwork activities	100	13 µSv/year to 1,5 mSv/year	2%
Production or use of components containing thorium	6	< 1 µSv/year to 82 mSv/year	35%
Production of zircon and baddeleyite, and foundry and metalwork activities	57	< 1 µSv/year to 2 mSv/year	15%
Production of phosphate fertiliser and manufacture of phosphoric acid	6	10 µSv/year to 0,5 mSv/year	0%
Treatment of rare earth elements and pigment production	3	65 µSv/year to 0,3 mSv/year	0%

[V] *ASN Report of 20 July, 2009 "Statement on management of waste containing technically-enhanced radioactivity" and ASN Report of 24 December 2009 "Assessment of exposure to ionising radiation in the professional industries and activities implementing raw materials naturally containing radionuclides not used for their radioactive properties: statement of the application of the Order of 25 May 2005 relating to these activities".*

[VI] *Robin des Bois reports: "Technologically technically-enhanced radioactivity" – 2005 and "Coal ash and phosphogypsum" – additions 2009.*

[VII] *Report IRSN/DRPH/DIR/2011-19 "Worker radiological protection - Professional exposure to ionising radiation in France: 2010 statement".*

The industries concerned by the Order of 25 May 2005 have been questioned for the 2012 edition of the National Inventory. For the others, some have been identified, but the declarations cannot be considered as exhaustive.

2.1. Industrial sectors concerned by the Order of 25 May 2005

Industries processing and transforming tin, aluminium, copper, titanium, niobium, bismuth and thorium ore

The ores concerned sometimes contain radionuclides, which are concentrated in the residue. These radionuclides, 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.

In the rare earth elements extraction sector, the RHODIA site at La Rochelle (Charente-Maritime district) has used monazite to produce thorium hydroxide. This production has generated LLW-LL radium-bearing residue (RRA), part of which has been transferred to a CEA storage facility at Cadarache (Bouches-du-Rhône district - approx. 5,570 cu. m). Very slightly radioactive general solid waste (RSB) is disposed of on site and makes up part of the backfill on the port at La Pallice (Charente-Maritime district) *(see chapter 4)*.

Finally, approx. 7,000 cu. m of LLW-LL RSB is stored on site: this is the largest part of the LLW-LL TENORM waste. Treatment of this waste to extract the rare earth elements is being studied.

The chemical industry extracts colour pigments for paint, such as titanium oxide, from natural ores or sand. The initial thorium and uranium activity levels may be concentrated in the residue. The Cristal Global Company manufactured titanium oxide on sites at Thann (Haut-Rhin district) and Ochsenfeld (Haut-Rhin district) and on its site at Le Havre (Seine-Maritime district). The waste produced is in the VLLW category (approx. 870 cu. m) or the LLW-LL category (approx. 80 cu. m). Similarly, Tioxide Europe manufactured titanium oxide pigments, whose production generated VLLW that is stored on the Calais site (Pas-de-Calais district).

The Rio Tinto Alcan Company extracted aluminium from bauxite, which generated deposits of red sludge on the site (rich in iron oxide) containing radium, in particular. This type of disposal (close to 8 million tonnes) is found on the shut-down sites at Aygalade, Barasse-Montgrand, Barasse-Saint-Cyr and Vitrolles (all in Bouches-du-Rhône district) as well as on the site still in operation at Gardanne (Bouches-du-Rhône district). On the Beyrede-Jumet site (Hautes-Pyrénées district), the waste produced is extracted dust, which is evacuated in ISD (conventional disposal installations) in compliance with the 2006 circular. The volumes of waste from this sector are presented in the le *table below*.

Industrial Company	Management solution	Volume (cu. m)
Tioxide Europe	VLLW	105
Cristal Global	VLLW	871
Cristal Global	LLW-LL	82
Rio Tinto Alcan	ISD	20
Rhodia	LLW-LL	7,580
CEA	LLW-LL	5,572

Industries producing refractory ceramics, and the glassware, foundry, steel and metalwork activities

Refractory ceramics mainly owe their natural radioactivity to the presence of zircon. This varies the radioactivity of the ceramic according to its quantity.

• The Savoie Réfractaire Company (in the Île-de-France and Rhône-Alpes regions), part of the Saint-Gobain group, produces ceramic coatings for different industries; the waste, which is zircon sand residue, is disposed of in ISD.

• The Thermal Ceramics de France Company (Loire district) produces fibres from zircon sand; the waste generated by the procedure is disposed of in ISD.

• The Imeyris at Ploemeur Company (Morbihan district) extracts and manufactures ceramic materials from kaolin ores. Most of the waste generated is disposed of in ISD, with the exception of a small volume for which the impact study showed that it should be disposed of at the VLLW disposal facility in the Aube district.

Industrial Company	Management solution	Volume (cu. m)
Société Savoie Réfractaire Groupe St-Gobain	ISD	160
Thermal Ceramics de France	ISD	80
Imerys Ceramics France	VLLW	6

Industries producing and using zircon and baddeleyite, mainly in the refractory and abrasive ceramics industry

Zirconium is used in alloys for nuclear fuel cladding.

• The Cezus Company (Isère district) produces the raw materials required for manufacture of the alloy and generates LLW-LL radium-bearing waste as well as waste that is disposed of at the VLLW disposal facility in the Aube.

• The Unifrax Company, established in Lorette (Loire district), produces fibrous insulation containing zircon. The waste resulting from manufacture of the fibres is regularly disposed of in ISD (150 tonnes in 2010).

• The Comptoir ores and raw materials company at Saint-Quentin (Aisne district), which transforms zircon sand for use in foundries, currently stores a small quantity (8 cu. m) of LLW-LL waste.

• SNECMA at Gennevilliers (Hauts-de-Seine district) uses zircon flour in the foundry process for aircraft engine parts. The waste generated is disposed of in ISD.

The quantities of this waste are listed in the *table below*.

Industrial Company	Management solution	Volume (cu. m)
Comptoir des minéraux et matières premières	LLW-LL	8
Cezus	LLW-LL	1,946
Cezus	VLLW	1,370
Unifrax	ISD	278
SNECMA	ISD	1

Industries producing or using components containing thorium

Certain industries handle thorium or its decay products. The radionuclides may simply be completely or partially transferred in the residues, or concentrated by precipitation phenomena related to the industrial processes implemented. Thorium improves steel heat resistance.

- The Messier foundry at Arudy (Pyrénées-Atlantiques district) manufactured thorium and magnesium based alloys for the aero industry. The waste from this production, declared in the Geographical Inventory, is LLW-LL type and is stored on the Arudy site (Pyrénées-Atlantiques district) awaiting evacuation.

- The Arkéma site located at Serquigny (Eure district) produced thorium nitrate from monazite and stores LLW-LL waste awaiting a final disposal or recycling solution.

Industrial Company	Management solution	Volume (cu. m)
Fonderie Messier	LLW-LL	27
Arkema	LLW-LL	1,604

The phosphate industry, particularly the manufacture of phosphoric acid and agricultural fertiliser production

The industrial processes for the production of phosphate fertiliser lead to production of solid waste (phosphogypsum), and also contaminated scrap metal when certain parts of the plants are eventually dismantled.

The Grande Paroisse Company has several sites in Haute-Normandie region (Rogerville, Grand-Quevilly, Anneville-Ambourville, Saint-Étienne-du-Rouvray, and Rouen (all in the Seine-Maritime district)) on which LLW-LL or VLLW are stored pending transfer to a final disposal location. Phosphogypsum is also disposed of on site. These sites are subject to regular monitoring.

With regard to the phosphogypsum disposed of in heaps (more than 25 million tonnes), recycling units processed this "secondary raw material" in the early 1980s to manufacture gypsum blocks for the building industry; one third of the phosphogypsum produced by the Grand-Quevilly plant (Seine-Maritime district) was absorbed in this way.

Part of the waste produced by PEC-Rhin at Ottmarsheim (Haut-Rhin district) which manufactured phosphoric acid was evacuated to ISD. Less than 10 cu. m of LLW-LL waste is stored on site.

Waste at the Boucau site (Pyrénées-Atlantiques district) in the Aquitaine region, where fertiliser was produced and monazite was milled, was sent to ISD or dealt with by Andra at the VLLW disposal facility in the Aube district, particularly in 2010.

Industrial Company	Management solution	Volume (cu. m)
PEC-Rhin	LLW-LL	10
Grande Paroisse SA	VLLW	64
Grande Paroisse SA	VLLW	4,000
Yara France	LLW-LL	120
Yara France	VLLW	100

Water treatment centres

Different procedures enable underground water intended for consumption to be filtered. The main process are filtration by sand, active charcoal or resin. The international bibliography on the subject mentions radon degasing at filtration installations or concentration of radionuclides in the filters.

The European bottling company at Donnery (Loiret district), for example, uses ion exchange resins to remove iron and manganese from the water. These resins are liable to concentrate radioactivity. Andra asked this company about the presence of TENORM waste on the Donnery site: no TENORM waste was declared by this site.

Thermal establishments

As in all water treatment installations, the procedures implemented in these establishments produce radon by degasing. The pipelines, filters or pumping equipment may concentrate the natural radioactivity of the water. In the statement prepared by the ASN (2009 report) only the exposure due to radon was assessed and no effective individual dose was adopted.

This sector is not yet included in the current issue of the *National Inventory*. Research work will be undertaken for the next issue.

2.2. Industrial sectors not concerned by the Order of 25 May, 2005

Certain sectors not concerned by the Order of 25 May 2005 are identified in the Robin des Bois report as being producers of technically enhanced radioactivity.

Industrial oil and natural gas extraction and processing facilities

Depending on the nature of the prospected terrain, sands, muds or certain tools may be contaminated by daughter products of the natural uranium in the subsoil. Total operated wells in the Aquitaine region: drums containing sludge, scale and sometimes gravel, contaminated with VLLW type uranium (approx.3 cu. m), are kept on the Saint-Faust sites (Pyrénées-Atlantiques district) listed in the Geographical Inventory. The waste that was stored on the sites at Lacq and Monein-Pont-d'As has been transferred to the Saint-Faust site (all in the Pyrénées-Atlantiques district).

Geothermal energy

With regard to geothermal energy, concentration of natural radioactivity seems similar to that in the case of gas and oil extraction: natural radioactivity is concentrated in pipelines (scale formation) or in the filtration systems. The GEIE company "Exploitation Minière de la Chaleur" (heat exploitation from mines) operates three bore holes 5,000 m deep on the Kutzenhausen site in Alsace (Bas-Rhin district). The VLLW waste (less than 1 cu. m) mainly from cleaning pipelines is stored awaiting evacuation.

The two sectors (paper industry and biomass combustion) are not included in this issue of the *National Inventory*. As in the case of “Thermal Establishments”, research work will be undertaken for the next issue.

The paper industry

The paper sector, identified in the Robin des Bois association study, may also be at the origin of TENORM waste production, depending on the manufacturing processes used. For example, the use of a chlorine-free bleaching process leads to the precipitation of barium chloride in the pipelines and in the screen filter at the first step of the paper pulp bleaching treatment. In principle, the measured dose rate values measured on contact can reach around 4.5 µSv/h, which may mean that these industries are not exempt.

Biomass combustion

In France the combustion of biomass, and in particular the use of wood as a fuel grew in the 1990s. The wood comes from forestry operations, saw mills or scrap lumber. Like ash from coal power stations *(see below)*, the ash from boilers concentrates radioactivity not only from natural radionuclides but also potentially from artificial radionuclides from fallout following the Chernobyl accident or from nuclear tests (strontium-90 or caesium-137).

3.
Residue from recycling processes

In addition to the industrial activities described in *paragraphe 2,* other sectors listed in appendix 1 of the Order of 25 May 2005 produce residues from recycling processes.

Thorium extraction installations

The RHODIA plant at La Rochelle (Charente-Maritime district) uses raw materials from ores that have been treated before their importation to France, to reduce the radioactivity. This activity produces suspended particulate matter (SPM) and crude thorium hydroxide *(see page 48)*.

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These suspended materials are considered to be recyclable radioactive materials *(see chapter 2)*. In fact, thorium is considered recyclable as it can be used in various industrial applications, particularly in the medical sector. RHODIA is now looking into processing crude thorium hydroxide. The quantities of waste that would result from this process are estimated at around 6,000 cu. m.

Industrial coal combustion plants

Ash is a natural by-product of burning coal in electrical power plants.

Coal contains several naturally radioactive substances (uranium, thorium and their decay products) present in very low quantities and concentrated in the ash after burning the coal. When this coal is burnt to produce electricity, 99% of the dust is captured.

The recovered fly ash is mainly used in the formulation for concrete with high added value. In fact, this additive lowers the core concrete temperature during setting, which limits cracking on one hand and also gives it good mechanical properties.

EDF and E.ON (formerly SNET coming from the affiliation of "Charbonnages de France" power plants in 1995) produce this type of ash and disposed of it on site in heaps.

E.ON and EDF have chosen to sell it. To recycle the ash and to satisfy the Ministerial Order of 25 May 2005, EDF carried out two studies to measure the exposure of workers and the general population.

The results from the studies concluded, with the worst assumptions, that worker exposure is about 0.14 mSv/year, and that of the population is 2 µSv/year for transfer in air, and less than 0.001 µSv/year for transfer in water.

Over the 2000-2009 period and taking all EDF and E.ON activities into account, the total production of coal ash represented an average of 1,400 kilotonnes and sales 1,800 kilotonnes. The extra 400 kilotonnes of sales in relation to production came from the disposal heaps.

These sales are distributed on average in the different use sectors as follows:

- ready to use and prefabricated concrete: 44%;
- cements and hydraulic binders: 25%;
- roadworks: 16%;
- injection works: 4%;
- backfill: 8%;
- miscellaneous: 3%;

To date, the total stock of EDF and E.ON ash is around 15 million tonnes distributed over the sites mentioned in the *table below*.

Only one E.ON site has non-recyclable ash stocks and is listed in the Geographical Inventory: Fuveau (Bouches-du-Rhône district).

EDF and E.ON sites storing recyclable ash

EDF sites
> Atton - Blenod-les-Pont-à-Mousson (Meurthe-et-Moselle district)
> Richemont (Moselle district)
> Woippy (Moselle district)
> Loire-sur-Rhône (Rhône district)
> Allennes-les-Marais (Nord district)
> Bouchain (Nord district)
> Champagne-sur-Oise (Val d'Oise district)
> Cordemais (Loire-Atlantique district)
> Saint-Leu-d'Esserent (Aisne district)
> Nantes (Loire-Atlantique district)
> Beautor (Aisne district)
E.ON sites
> Hornaing (Nord district)
> Saint-Avold (Moselle district)

Thermal electrical power plants generate coal ash.
This production is made up of 90% fly ash and 10% hearth ash.
Their recycling processes are the following:

Cement and concrete	Fly ash	- Damp fly ash: added to raw mixtures. - Dry fly ash: added directly to cement or concrete to up to 20% concentration. 80% of the fly ash produced is certified under standard EN450*.
Road techniques	Hearth ash	- Backfill, platforms, road sub-layers. *Noteworthy examples:* LGV lines, Metz-Nancy airport, 'Port 2000' at Le Havre.
Other	Fly ash and and hearth ash	- Cement (approx. 10%) and fly ash binders for filling cavities such as at Till (Meurthe-et-Moselle district) or the 'Grand Stade' de Lille (Nord district). - Grout for trenches: this method permits to excavate narrower trenches in towns and enables them to be closed more quickly.

** Standard EN 450 defines the physical and chemical characteristics and the quality control processes for fly ash, which is to be added to concrete, mortar or grout.*

The other sites identified in the 2009 Robin des Bois association report are not mentioned in the *table on page 143* as the ash has been removed and the ground covered with topsoil.

In addition to the previously mentioned sites, there are 24 other sites on which coal ash is stored. These sites are essentially orphan sites and are not declared by an operator. A presentation of these sites will be made in the next issue of the *National Inventory*.

Restored EDF ash disposal sites

ALBI (Tarn district) A small amount of ash remains (remainder of heap) and will be covered with topsoil in 2012	**PONT-SUR-SAMBRE (Rhône district)** This site has been re-planted before its sale to the group of municipalities of Maubeuge.
COMMINES (Nord district) The ash removal is complete. Backfilled and covered with topsoil. The land is being given back to the municipality.	**PORCHEVILLE (Yvelines district)** There is very little ash remaining on this site, vegetation has returned naturally.
GONFREVILLE-L'ORCHER (Seine-Maritime district) The ash removal is complete. The land has been returned to the 'Grand Port Maritime du Havre'	**VAIRES-SUR-MARNE (Seine-et-Marne district)** The ash has been treated and covered with earth. Construction of an Industrial Site is scheduled.
LA GRANDE-PAROISSE (Seine-et-Marne district) There is no ash on this EDF site	**VITRY-SUR-SEINE (Val-de-Marne district)** The ash has been removed.

4. TENORM waste stock at the end of 2010

TENORM waste to be taken over by Andra

Category	Volume in cu. m conditioned equivalent
LLW-LL	17,000
VLLW	7,800
Total	**24,800**

Approximately 40 million tonnes of TENORM waste (excluding coal ash) have been disposed of in legacy sites *(see chapter 4)*.

Of all the waste taken over by Andra, approx. 17,000 cu. m of TENORM waste is LLW-LL and 7,800 cu. m is VLLW.

Existing and planned solutions in France for management of radioactive waste

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1.
Treatment and conditioning of radioactive waste

To be accepted in a storage or disposal facility, waste packages must have characteristics compatible with environmental and human protection (physical and chemical stability, confinement of the substances they contain, etc.).

These characteristics are defined by the operator of the receiving installation in agreement with the rules set out by the Nuclear safety authority (ASN). Some concern the type of waste or its radioactive characteristics: for example, the disposal of liquids, fermentable waste or flammable materials is prohibited.

Other characteristics relate to the final item to be received, i.e. after treatment and conditioning of the initial waste: for example, dimensions, mechanical fall-resistance, permeability, etc.

Treatment

This consists in transforming the waste from its initial form to a form displaying characteristics that are more suited for long-term management, and in reducing its volume as much as possible.

Furthermore, the waste must have radioactivity confinement properties over variable durations depending on the category of the waste and the intended type of disposal.

In this regard, in general the waste should be conditioned.

Treatment procedures

- Treatment of liquids is aimed at concentrating the radioactivity in a smaller volume (concentration by evaporation) or by trapping the bulk of the radionuclides using chemical reactions.
- 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 are often compacted prior to conditioning.

Conditioning

In general, conditioning consists of immobilising the waste in a container that contributes to confinement of the waste and retention of the radionuclides.

Very often, and depending on the physical and chemical properties of the waste, it is necessary to mix it with a material called a 'matrix' which confines the radioactivity more effectively.

The matrix/waste combination is placed in a suitable container.

The most radioactive waste, solutions of fission products and minor actinides, comes from the processing of spent fuel. It is conditioned in a glass matrix.

For intermediate or low level radioactive waste, cement-, polymer- or bitumen-based materials are used.

Containers are made of concrete, non-alloy steel (ordinary steel) or stainless steel.

Very-low-level waste is generally conditioned to make it easier to handle. However, it is not always necessary to containerise the waste if it is in a form that makes it safe for direct disposal.

Nowadays, the waste producers are responsible for defining and implementing the conditioning modes for most of the waste they produce, subject to agreement by Andra and under ASN control.

In certain special cases, legacy waste, which was either treated in line with the standards in force at the time, or stored in bulk in facilities, must be recovered for conditioning, reconditioning or stored under improved conditions, depending on the case. This is referred to as waste recovering and conditioning (RCD). The 28 June 2006 Act stipulates that intermediate level, long-lived waste produced before 2015 must be conditioned by its owners by 2030 [I].

Unloading big bags of VLLW waste

[I] *Article 7 of Planning Act 2006-739 of 28 June 2006, on long-term management of radioactive materials and waste.*

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

Research carried out in the nuclear power sector led to the treatment and conditioning processes that enable reductions in the volume of waste to be stored or disposed of.

To quote a few examples. In the case of ILW-LL, it is often compacted, which enables the volume of the spent fuel structure waste to be reduced by a factor of 4. This waste was previously embedded in cement without compaction.

Recycling effluents from the AREVA NC plant at La Hague (Manche district) and sending the residual output for vitrification contributes to significantly reducing the output of bituminous product waste. Optimisation of the effluent treatment and conditioning procedures has enabled the annual volume of HLW and ILW-LL to be reduced by a factor of 6: from initial levels of about 3 cu. m per tonne of treated fuel at the La Hague plant treatment workshops, to less than 0.5 cu. m now.

Compacting a drum of ILLW-SL

Hull compacting unit (ACC) in the AREVA plant at La Hague (Manche district)

2.
Radioactive waste management solutions

The National plan for management of radioactive materials and waste (PNGMDR) [II] describes the management solutions for the different categories of radioactive waste.

These management solutions consist of four types of disposal facility: two are 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.

Before being disposed of, waste is generally stored in dedicated installations.

A storage facility is a safe installation that optimises management of waste flows to existing or planned final disposal or recycling solutions on the one hand, and maintains the waste in a safe condition pending conditioning and/or acceptance for disposal on the other hand.

The storage function may be:

- **for waste to be sent to existing disposal facilities:**
  - logistic style storage, enabling flows to the Andra installations to be managed,
  - waste storage, in particular legacy waste, pending conditioning before disposal;
- **for waste to be sent to future disposal facilities:**
  - storage pending the availability of the disposal solution,
  - for waste with high levels of activity, to be stored several decades to decay and cool, before being taken to a deep repository.

2.1
HLW and ILW-LL

Currently there is no final solution for HLW and ILW-LL.

However, the Planning Act 2006-793 of 28 June 2006 entrusts Andra with the task of conducting studies and research for selection and design of a deep reversible disposal facility.

Andra therefore bears the responsibility for the project of deep geological repository, Cigéo, which will receive radioactive waste that cannot be disposed of on or near surface for safety or radiological protection reasons.

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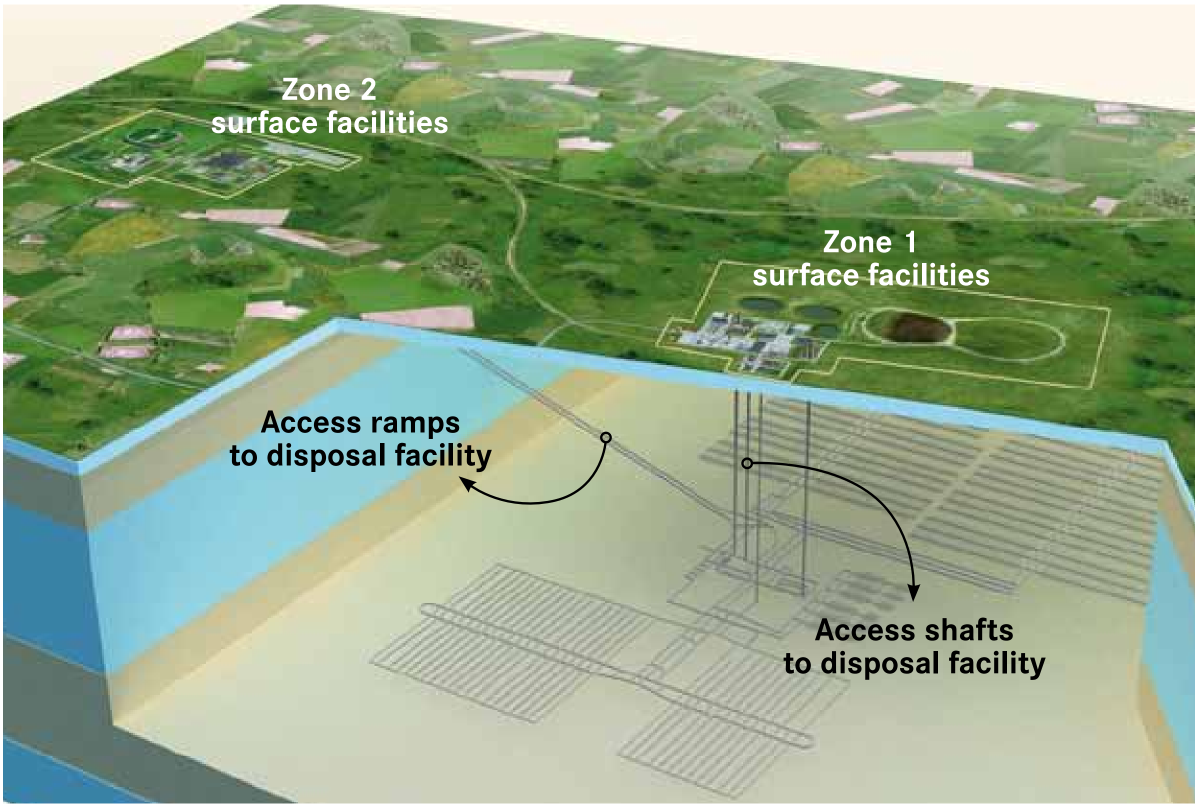
[II] *PNGMDR (National plan for management of radioactive materials and waste), available on the website www.industrie.gouv.fr/energie/nucleair/pngmdr.htm*

Commissioning is scheduled for 2025, subject to licensing requirements. 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.

Underground disposal facility will be constructed in the Callovo-Oxfordian argillite formation currently studied by the Meuse/Haute-Marne Underground Research Laboratory.

Temporary storage is an essential tool for managing HLW and ILW-LL waste whilst waiting for Cigéo to open.

Storage can be used, for example, in the management of vitrified waste containing fission products and minor actinides (CSD-V) and produced from processing of UOX fuels. The packages have to be kept in ventilated pits in the EV-SE disposal facility at the Hague plant (Manche district) for approx. 60 years to reduce their thermal power and satisfy the specifications for deep disposal.



Layout of the Cigéo installations

2.2
LLW-LL

The Planning Act 2006-793 of 28 June 2006 tasked Andra with developing shallow disposal facilities for graphite waste mainly coming from operation and dismantling of first generation GCR reactors and for radium-bearing waste.

The search for a site for installation of a shallow disposal facility was launched by Andra, with Government approval, in June 2008.

The government also tasked Andra with examining the possibilities of including other low level activity, long-lived waste (LLW-LL) in the inventory.

Two design options were considered.

The first option is called **"disposal with reworked capping"** (SCR) which consists of installing the disposal facility at a depth of around fifteen metres in a mainly clay layer with low permeability. After excavation down to the disposal level, cells are dug into this clay. Once filled, they are covered with a layer of compacted clay coming from the site excavation, then with a protective vegetation layer reconstituting the natural site level.

This option is mainly applicable to radium-bearing waste.

In the second option, the disposal cells are arranged in the middle of a thick clay formation at a depth of 50 to 200 metres. Access is via a ramp and once the waste is disposed of, the drifts are backfilled. This option is called **"disposal with intact capping (SCI)".**

At the end of 2008, around forty municipalities had shown interest in this project. In 2009, two municipalities were selected for geological investigations aimed at checking the feasibility of this type of disposal. During the summer of 2009, the municipal councils of both municipalities decided to withdraw their candidature under pressure from the opposition. The government and Andra acknowledged these decisions.

In this context, the government has announced a shift of the project schedule to give time for consultation and asked Andra to pursue discussions with the territories where municipalities had expressed their candidature.

The government has also requested Andra to reopen the different radium-bearing and graphite waste management options, in particular studying the possibility of separate management for these two types of waste. A statement of the work will be submitted to the government by Andra at the end of 2012.

The High Committee for transparency and information on nuclear safety (HCTISN) set up a working group to provide feedback on the process of searching for a LLW-LL site. This analysis was carried out in collaboration with the ANCCLI[1].

Whilst awaiting a disposal solution for this LLW-LL, the packages are stored in various installations. The main producers have their own storage installations. The waste from "small-scale nuclear activities" waste producers, which Andra deals with, is stored in several of the main nuclear operators' installations. Some of these installations can no longer house them and waste must be removed. Andra has therefore scheduled the construction of a new storage facility on the VLLW disposal facility that it operates in the Aube. Commissioning is scheduled in 2012 *(see box on page 155)*.

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1 *ANCCLI: National association of local information committees and commissions.*

2.3
LILW-SL

Low and intermediate level, short-lived waste (LILW-SL) has been disposed of on the surface since 1969.

The aim of this disposal is to isolate the radioactive products from the environment for the time necessary for decay of their radioactivity down to negligible impact levels. There are two sites of this type in France: the CSM disposal facility in the Manche district and the LILW-SL disposal facility in the Aube district.

The CSM in the Manche district has not received any waste since 1994 (527,000 cu. m was disposed of there) and it is in a monitoring phase, whereas the LILW-SL disposal facility in the municipality of Soulaines-Dhuys (Aube district) has been active since 1992.

These centres are classified as basic nuclear installations (INB). The LILW-SL disposal facility in the Aube district covers a surface area of 95 ha, including 30 reserved for disposal, and has a licensed capacity of one million cubic metres of radioactive waste packages.

The LILW-SL disposal facility in the Aube district

The wast disposal facility in the Manche district (CSM)

At the LILW-SL disposal facility in the Aube district, the packages are disposed of in reinforced concrete structures, 25m long and 8m high.

The packages are protected from rain during filling of the cells by mobile roofs.

When a cell is filled, it is closed with a concrete slab and covered with a layer of impermeable polyurethane.

The sealing of these cells is checked via a network of underground tunnels which are regularly inspected.

The disposal structures are built on a geological zone made up of a clay layer overlaid with a sandy layer.

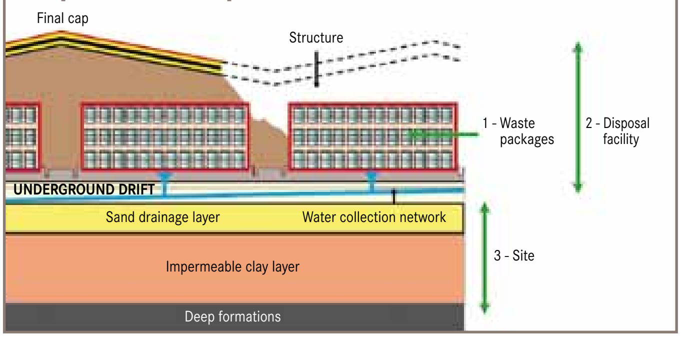
The clay layer is impermeable and constitutes a natural barrier in case of accidental dispersion of radioactive elements in the subsoil.

Above the clay, the sandy layer drains rainwater to a single outlet, which facilitates environmental monitoring.

Lowering a concrete package into a cell (LILW-SL disposal facility)

Cement matrix waste drum and cement matrix waste concrete package

Cross-section diagram of the LILW-SL disposal concept



VLLW waste conditioned in big bags

Aerial view of the VLLW disposal facility in the Aube district

2.4
VLLW

On request from the authorities, Andra developed a specific solution for very-low-level waste, inspired in principle by the disposal installations for the chemical industry's hazardous waste.

This very-low-level waste disposal facility is an installation classified for environmental protection (ICPE) and was licensed for operation by Order 03-2176 A of 26 June 2003. It has been operated by Andra since the summer of 2003.

To avoid early saturation of the facility, ways of optimising the management of VLLW are being studied, such as, for example, recycling of metals and concrete from dismantling of nuclear installations.

Collection and storage of waste at Morvilliers (Aube district)

The insufficient capacity of the current solutions and dependence on other industrial operators has for some time led Andra to consider the benefits of owning its own facilities, which would enable it to perform its role of taking waste from the "small-scale nuclear activities" waste producers and in particular storing waste intended for disposal facilities.

The following developments also add to the considerations:

- The announcement by the CEA of the dismantling of the 'Centre de Regroupement Nord' at Saclay (Essonne district);
- The announcement by SOCATRI (Drôme district) of the need to modify the building currently in use as well as the general operating rules and their disposal licenses to be able to continue to meet needs;
- the target set for Andra, via the PNGMDR, to take over the waste from 'small-scale nuclear activities' waste producers, mainly lightning conductors and smoke detectors, within the next 10 years.

Within this context, Andra has undertaken construction of a collection and storage installation, in the form of two separate buildings, at the VLLW disposal facility:

- one building for storage of the LLW-LL waste currently stored at various installations (SOCATRI (Drôme district), INB 56 at Cadarache (Bouches-du-Rhône district), INB 72 at Saclay (Essonne district), etc.) and which, for various reasons, cannot remain stored while awaiting commissioning of the LLW-LL disposal facility;
- the other for gathering waste collected from the 'small-scale nuclear activities' waste producers, and forwarding it to the appropriate waste treatment, storage or disposal installations. This function is currently performed by the 'Centre de Regroupement Nord' (CRN) at CEA/Saclay (Essonne district).

This installation should be commissioned at the end of 2012.

The VLLW disposal facility covers an area of 45 ha, located for the most part within the municipality of Morvilliers (Aube district). It is designed to accommodate 650 000 cu. m of waste, mainly from the dismantling of decommissioned French nuclear facilities.

Waste packages are inspected upon arrival and disposed of 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 cap, also of clay, placed over the waste.

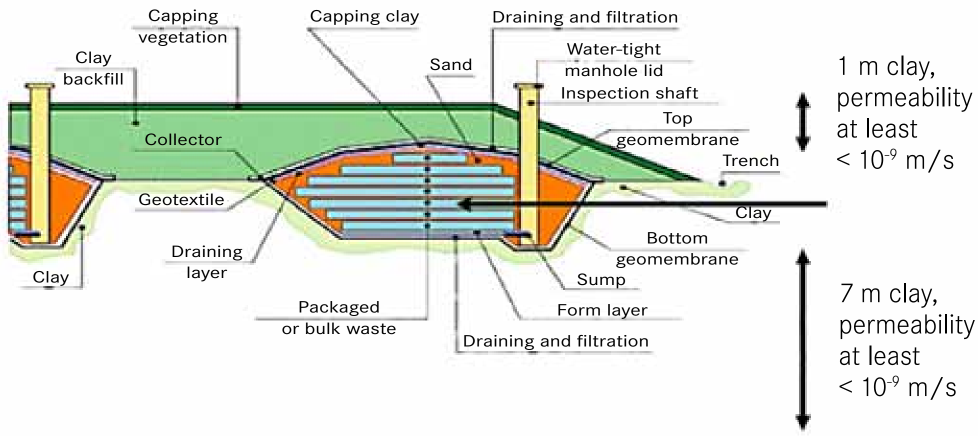
During operation, the cells are protected by tunnel-shaped removable structures and are equipped with monitoring devices.

Very low-level waste lies between conventional waste as defined in article L. 541 of the Environment Code and low-level waste (LILW-SL or LLW-LL), because France, unlike other countries, has no preset clearance limits for waste that is or is likely to be very slightly radioactive.

Limits can be set for disposal acceptability depending on the radionuclides.

VLLW disposal cell

Cross-section diagram of a CSTFA disposal cell



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2.5 Tritiated waste (LILW and VLLW)

Even though tritium is a short-lived radionuclide, it is difficult to confine and can easily migrate into and mark the environment.

Tritiated waste is specially managed. Most of it is solid. Liquid or gaseous waste, produced in very low quantities, must be treated and stabilised before coming to the storage facility.

After fifty years of storage, and depending on its radioactivity and residual degasing rate, this waste is sent to an appropriate disposal facility.

This waste is mostly the result of nuclear deterrent activities (> 95% by volume).

Also, industries and medical and pharmaceutical research laboratories have used and still use tritium for different applications which generate tritiated waste, a limited quantity of which must be stored before final elimination.

Finally, the ITER installation will also generate tritiated waste from 2024 and will become the main contributor to the inventory, initially in its operational phase and then, from 2055, in its dismantling phase.

The waste can be classified into six categories:

- waste exclusively containing tritium:
  – very low level waste,
  – waste that gives off very little gas,
  – waste that gives off gas,
- mixed tritiated waste, i.e. associated with other radionuclides:
  – tritiated uranic waste,
  – short-lived irradiating tritiated waste,
  – long-lived irradiating tritiated waste,

The sizing criterion for storage of this waste with regard to radiological protection is the level of gas given off by the tritium. This then involves design of a storage facility with different modules and ventilation adapted to the level of gas given off by the waste.

Also, to limit transport of this type of waste, it has been decided to store the waste as close as possible to the installations producing it.

The CEA has built a first storage module to store its waste at Valduc (Côte-d'Or district), which should be commissioned at the end of 2012 to receive very-low-level tritiated waste.

With regard to ITER, the first modules will be available in 2024 for VLLW waste and short-lived irradiating waste.

The tritiated waste coming from 'small-scale nuclear activities' waste producers is pure tritiated waste giving off little gas, which the inventory currently identifies as representing slightly more than 20 cu. m at the end of 2010 and around 100 cu. m by 2060.

This waste is currently on the production sites. In case of a public health or environmental emergency and after agreement from the relevant safety authority, it may be stored temporarily on the Valduc site (Côte-d'Or district) (INBS).

It should be noted that for the immediate requirements of the different entities of the Group, Thalès Air Systems has developed a temporary storage solution at its site at Fleury-les-Aubrais (Loiret district), with the capacity to receive 10 cu. m of tritiated waste.

Eventually it is planned to use the ITER operational waste storage infrastructure to deal with tritiated waste from "small-scale nuclear activities" waste producers.

2.6
Waste stored on site for radioactive decay-special case

Most of the waste stored to allow radioactive decay is hospital waste containing very short-lived radionuclides used for diagnosis or treatments.

This waste is simply stored until its radioactivity decays for durations varying from a few days to a few months.

The corresponding waste is then evacuated for conventional disposal. It is no longer considered as radioactive waste.

Foreign inventories of radioactive waste

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1.
The purpose of waste inventories

In a large number of countries operating nuclear installation, the entities involved have established a precise assessment of the radioactive waste and spent fuel they produce. It involves qualified and regular monitoring covering the treatment, transport, disposal and disposal phases.

The countries also prepare inventories reporting on the volumes and situations of radioactive waste produced, also supplying other information on their location or their radioactivity. These are published regularly, in particular by the signatories of the IAEA common convention on spent fuel and radioactive waste management safety.

According to the US *Government Accountability Office* (GAO) [1] report produced in 2007 [I]: 18 countries (including France, Japan, Germany, Canada, etc.), using their National Inventory database of radioactive waste, have produced:

- an inventory of all radioactive waste by type, volume, location and producer;
- an inventory of the condition and use of the sealed radiological sources held.

These countries have designated a national authority to manage the inventory database:

- enabling the exhaustiveness and accuracy of these databases to be checked;
- requiring waste producers to submit information for the waste inventory to the national authority at least once a year;
- using the inventory database to draw up forecasts of volumes of waste that will be produced and informing the public about the volumes of waste to be stored and disposed of.

The European Community has undertaken an assessment of its Member States [II].

This study gives an overview of the implemented national waste data monitoring systems amongst the European Union Member States. It establishes recommendations for future waste management systems. The study covers collection, publication and management of radioactive waste and spent fuel data in the European Union Member States and candidate countries listed in the *table on the next page*.

1 *United States Congress organisation in charge of audit, assessment and investigation of public accounts.*

[I] *LLRW management, GAO-07-221.*

[II] *"Radioactive Waste and Spent Fuel Data Collection, Reporting, Record Keeping and Knowledge Transfer by EU Member States Final Report BS-Project No. 0707-03 Contract No. TREN/07/NUCL/S07.78807".*

Type of national inventory database of radioactive materials and waste

Response	Country
Central computerised database with electronic submission of data	Germany, Belgium, Croatia, Spain, Estonia, Finland, France, Hungary, Italy, Latvia, Macedonia, Netherlands, Romania, Slovenia, United Kingdom
Computerised database located at the nuclear power plant	Lithuania
Central computerised database with network submission of data	Czech Republic
Central computerised database with data collected on paper forms	Bulgaria, Slovakia
Central hardcopy archive with data collected on paper forms	Greece
Not mentioned	Austria, Cyprus, Denmark, Ireland, Luxembourg, Malta, Poland, Sweden, Turkey

Source UE: BS-Project No. 0707-03 Contract No. TREN/07/NUCL/S07.78807

All these countries have regulatory specifications concerning maintaining a national data collection system on waste and spent fuel. The allocation of responsibility for maintaining an inventory is generally specified in the regulation framework.

The national data collection system is organised in different ways according to the importance of the nuclear program of the concerned country and the waste management set up. The *table on the next page* shows the objectives of the countries to produce inventory databases for their radioactive waste. It is clear that management of installation capacities is one of the major concerns.

Countries' objectives for production of inventory databases

Country	Policy decisions	Public information	Management plan	Security	Financial management	Technical management
Austria			x	x	x	x
Belgium	x	x	x			x
Bulgaria		x	x	x	x	x
Croatia	x	x	x	x	x	x
Cyprus	*Not communicated*					
Czech Republic	x	x	x	x	x	x
Denmark		x	x	x		x
Estonia	x		x			
Finland	*"The main objectives of the database are: I) To support the regulations on waste and the associated inspections; II) To provide regular progress statements to the ministries; III) To inform the public"*					
France	x	x	x			
Germany	x	x	x		x	
Greece	*Not communicated*					
Hungary	x	x	x	x	x	x
Ireland	*Not communicated*					
Italy		x	x			
Latvia	x	x	x	x	x	x
Lithuania			x			x
Luxembourg						x
Macedonia		x	x	x	x	x
Malta	*Not communicated*					
Netherlands	*Not communicated*					
Poland	*Not communicated*					
Portugal	*Not communicated*					
Romania		x	x		x	x
Slovakia		x	x		x	x
Slovenia	x	x	x	x	x	x
Spain	x		x	x	x	x
Sweden	*Not communicated*					
Turkey	*Not communicated*					
United Kingdom	x	x	x			x

Source UE: BS-Project No. 0707-03 Contract No. TREN/07/NUCL/S07.78807

2.
New European directive on the management of spent fuel and radioactive waste (2011/70/Euratom)

The Council of the European Union adopted directive 2011/70/Euratom of the Council on 19 July 2011 establishing a community-wide framework for responsible and safe management of spent fuel and radioactive waste from production through to disposal. It completed the legislative instruments of Euratom that had not yet covered this subject.

It makes Member States and the producers responsible for the safe management of fuel and waste as well as for protecting people and the environment against the dangers of ionising radiation. It requires the Member States to provide a legal framework on their nuclear safety to set up:

- a competent safety and inspection authority, Independent from waste producers;
- license holders able to demonstrate and maintain the safety of their installations in terms of spent fuel and waste management throughout its life.

It also requires the Member States to set up a national programme to produce and implement a fuel and waste management policy including:

- general objectives that the national policies of the Member States have to reach in terms of spent fuel and radioactive waste management;
- important deadlines to meet for reaching the national programme objectives;
- an inventory of all spent fuel and radioactive waste and estimates in relation to future quantities, including those resulting from decommissioning operations. This inventory should clearly indicate the location and quantity of radioactive waste and spent fuel in compliance with the appropriate classification of radioactive waste.

The Member States must also:

- provide the necessary financial resources to manage spent fuel and waste;
- maintain adequate human resources;
- provide transparency of information and public participation;
- regularly re-examine and update their national programme to take developments and progress into account, and organise peer reviews;
- favour disposal of waste in the producing Member State, but be able to dispose of their waste in another country (EU Member State, or under certain conditions, other country).

This directive came into force on 23 August 2011 and Member States have two years to transpose it into their national legal framework.

In its preamble, the directive mentions that geological disposal is the reference solution for intermediate level long-lived and high-level waste. In fact, in the majority of countries, geological disposal has been adopted as a long-term solution. Various host rock formations are used according to the geological possibilities of the concerned country.

3.
Monitoring performed by the International Atomic Energy Agency (AIEA)

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 are 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 [III].

Waste volumes remain as indicated by each country; crude, treated, conditioned, stored or ready for disposal.

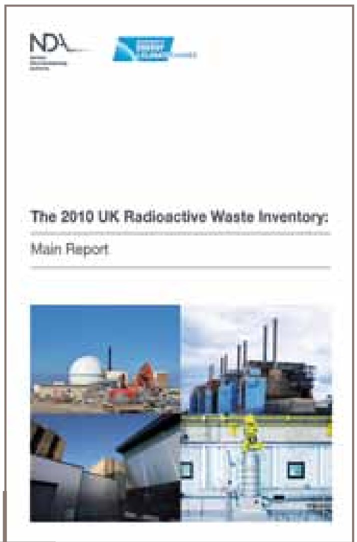
Every three years Member States publish a national report under IAEA supervision within the framework of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. The most recent conference took place in May, 2012 at the IAEA headquarters in Vienna (Austria). A significant part of these reports is devoted to updating figures on existing radioactive waste and spent fuel inventories.

4.
Inventories in particular countries

4.1.
UNITED KINGDOM

In the United Kingdom, an inventory is compiled every three years by the new nuclear decommissioning authority, the NDA, in partnership with the Department of Energy and Climatic Change (DECC).

The 2010 inventory, published in 2011, is the latest applicable version. This inventory presents the status of radioactive waste in existence on 1 April 2010 and provides a list of all waste to be produced in the United Kingdom.



The UK Inventory

[III] *IAEA Safety Standards Series No GSG-1, 2009.*

This inventory includes information on waste quantities, categories and characteristics. Forecasts are based on various assumptions regarding electricity production, decommissioning plans and other operations. With the exception of the low-and-intermediate-level, short-lived waste disposal facility close to Drigg, not far from Sellafield, no nuclear facility contains radioactive waste other than that produced by the facility itself. The 2010 inventory is based on the examination of 1,312 sites and includes Defence activities. It takes into account actual and forecast waste, mainly located near the production site and not yet subject to final disposal. This inventory therefore only lists waste already in storage or to be produced. It does not include the 800,000 cu. m of waste disposed of at Drigg. The volumes listed in the inventory mainly correspond to the condition of the waste when inventoried, i.e. the volumes occupied in reactor vessels (case of liquids to be treated), cells, silos, drums, etc. containing them.

The inventory is presented in the form of several documents:

- a statement of the 2010 inventory which targets a large audience. It provides information on the definition and nature of radioactive waste in the United Kingdom: How is it produced? How much is there? How is it managed?
- a main inventory report which gives detailed information on the weight, volume, conditioning and packaging of waste. It details the waste produced and to be produced, in comparison with the 2007 inventory;
- an inventory summary for international publication which responds to the international declaration requirements for radioactive waste at 1 April, 2010. It Is based on the United Kingdom classification of waste both for long-lived and short-lived radioactivity.

4.2. SWITZERLAND

In a context of relatively modest nuclear activity, Switzerland compiled a first inventory of its waste in 1984 via Nagra (cooperative company for radioactive waste disposal). Updated in 1994, 2008 and again in 2012, the publication reflects the content of the MIRAM database (“Radioactive material inventory database”) created to meet the needs of waste management organisations.


nagra
Technischer
Bericht 08-06
Modellhaftes Inventar
für radioaktive Materialien
MIRAM 08

The Inventory for Switzerland

This inventory lists all the 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 a periodically updated version in connection with the progress on the selection procedure for disposal facilities ('sector plan').

4.3. BELGIUM

Ondraf, the national organisation for radioactive waste, is responsible for producing an inventory in two parts; one for radioactive substances present on Belgian territory and the other for 'nuclear liabilities' which lists the different sites and producers of radioactive waste.

This task was entrusted by Royal Order on 16 October 1991 and was extended to all sites and producers by the Act of 12 December 1997.

Ondraf keeps permanently up to date a quantitative and qualitative inventory of all existing and future radioactive waste, including unused fissile materials and future waste from dismantling of nuclear installations.

The inventory is issued every five years and the last one, published in 2008, covered the period 2003-2007.

It identified 824 sites containing radioactive waste, radioactive materials from dismantling and nuclear materials.

It provides a list of forecast waste volumes up to 2070, the date by which all existing nuclear facilities will be dismantled. The inventory identified non-nuclear sites such as the one at Olen that contains radium-bearing waste from ore processing, 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 for the country in case of lack or absence of the 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, consists of:

(source: Ondraf internet site www.nirond.be)

- "Identifying the location and status of all nuclear facilities and all sites containing radioactive substances, with a radioactive substance defined as "a 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 clean-up 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 the 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 synthesis is available on the Ondraf website.

The third inventory report will be published in 2013 for the nuclear liability part, and in 2012 for the radioactive waste part. This last part groups waste physical, radiological and chemical data.

4.4. 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. After the end of the 15th legislature, implementation of the plan was not pursued.

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.

It collects and updates radioactive waste inventory data, including existing waste quantities and volumes, as well as forecasts for the next year and for each decade up to 2080.

The 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.

Potentially releasable waste, as defined by German radiation protection regulations, depleted uranium and recycled uranium and plutonium used to make fuel assemblies are not included in the inventory.

However, the recycled uranium and plutonium are accounted for annually by the Ministry of the environment, preservation of nature and nuclear safety (BMU). Inventory data concerning current and future waste production volumes is supplemented with chemical data giving the organic and inorganic composition of waste and dangerous substances in relation to the preservation of underground water.

Radioactive waste production forecasts are established by the BfS in accordance with a scenario modified by the 13th amendment, of 6 August 2011, to the Nuclear Power Act. With this amendment, passed following the events in Japan in 2011 that led to reconsideration of the risks related to nuclear power, eight nuclear power plant operating licences have not been renewed. The operating licences for the nine remaining reactors come to an end between 2015 and 2022. The complete German radioactive waste inventory is not yet available to the public (not all aspects of its presentation are covered). This could be addressed by the future National radioactive waste management plan, where the choice of the future disposal facility for exothermic waste remains to be defined. An inventory is presented every three years in the Federal Republic of Germany report, under IAEA supervision, for the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. It was published in 2011 in preparation for the 4th conference of the Joint Convention held in May 2012.

4.5. 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 first general Plan for radioactive waste.

Today, this information is compiled in a database used to produce a synthesis 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 managed in Spain. The data are presented by type of producer. They include fuel assemblies, reactor waste data and waste data at the El Cabril disposal facility.

They indicate the waste volumes already produced and to be produced in Spain for which treatment and storage takes place abroad. Residues from former mining installations are also included in the inventory.

Royal Order 1349/2003 of 31 October 2003 regulates the activities and financing of Enresa. This public organisation is responsible for producing an inventory of radioactive waste stored and disposed of, including that from dismantled or decommissioned facilities.

The contract established between waste producers and Enresa obliges producers to supply an initial inventory presenting the real situation of the radioactive waste, by type and quantity, at the time of signing the contract. In addition, the producer must indicate every year:

- 5-year forecast estimates of radioactive operating waste to be produced, classified by family;
- 10-year forecast estimates of the types of fuel;
- 5-year forecast estimates of specific radioactive waste;
- inventories of the waste produced the previous year, by family (operating waste, spent fuel and specific waste);
- the future facility decommissioning programme.

A national database of radioactive waste and spent fuels is kept up to date by Enresa.

Its main purpose is to contribute to the operational and strategic planning of waste management. This inventory is not directly and publicly published by Enresa. However, it is described in the IAEA's NEWMDB and in the Spanish National report published for the 4th Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management organised by the IAEA.

4.6. USA

Several radioactive waste inventory and monitoring systems are used in the United States, varying according to the responsible regulating organisation:

- the *Department of Energy* (DOE) for the Defence sector;
- the *Nuclear Regulatory Commission* (NRC) for the commercial sector.

Disposal facilities are often determined by the origin of the waste.

The NRC compiles national inventories for spent fuels and sealed radioactive sources for the commercial sectors.

For other waste categories, there is no single national inventory that pools information on all facilities and organisations, whether producers, an intermediary in waste management (broker or processor) or a disposal facility manager.

However, producers of waste from the commercial nuclear sector establish manifests for sending waste to the intermediaries ("Manifest Information Management System"). The waste from several producers may therefore be collected together before treatment and disposal. Operators of the disposal facilities keep the data for the service life of the facility and organise archiving after closure.

Radioactive waste is disposed of both by Federal Government Agencies and by private organisations. Later, disposal facilities managed by private organisations will be placed under the responsibility of State or Federal authorities. Spent fuel and high-level waste is stored.

Specifications regarding inventories depend on the State or Federal legislation applicable to each disposal facility. 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 in disposal facilities.

For the Defence sector, the DOE **(www.em.doe.gov)** also has its own specific inventory systems, including the following:

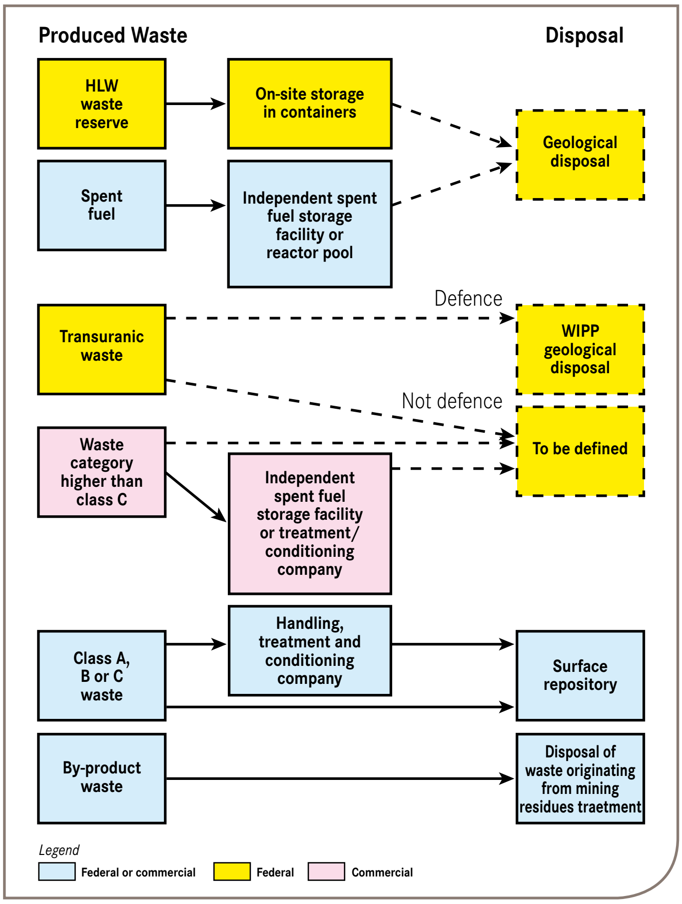
- solid Waste Information Tracking System (SWITS), used for solid waste, LILW and transuranic waste of the Hanford site;
- integrated Waste Tracking System (IWTS) implemented in the Idaho National Laboratory;
- waste Isolation Pilot Plant Waste Information Management System (WWIS) which constitutes the inventory (transuranic waste) of the first commissioned geological repository.

Often very exhaustive, the American inventories list all the activities generating radioactive waste: mining waste, clean-up waste and hybrid low-level waste that is both radioactive and chemically toxic.

This information can often be freely accessed through databases available on the Internet, in particular the WIPP one, operated by the DOE.

Finally, the DOE prepares a synthesis of inventory data on nuclear facilities. It is published in the national report submitted to the IAEA (International Atomic Energy Agency) in accordance with the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. It is also updated in the NEWMDB inventory database used by the IAEA.

Illustration of radioactive waste management in the United States



Report
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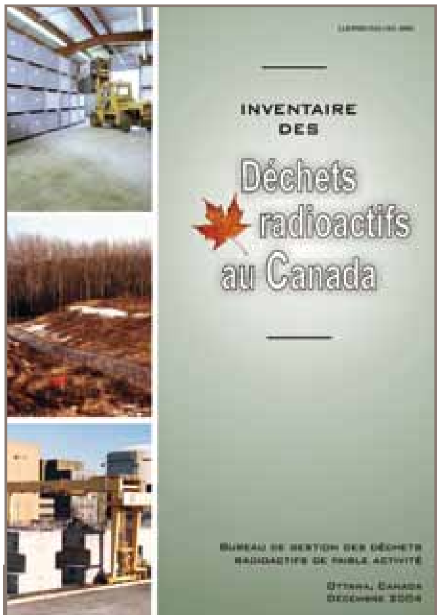
4.7.
CANADA

Every three years, Canada 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 the operation life for the current reactor fleet, planned in 2050.

The radioactive waste inventory data comes from several sources. It is taken from regulatory documents, reports and information provided by the regulatory organisation, waste producers and waste management facilities.

The regulatory document comprises: annual and quarterly compliance reports, annual safety examinations and decommissioning reports submitted to the safety authority (CCSN).



The Canadian Inventory

Finally, each licence holder must produce and implement an accounting system based on radioactive waste and spent fuel. This system and the associated registers are subject to regulatory monitoring.

The radioactive waste is classified according to three categories, corresponding to the different waste management policies implemented in Canada:

- nuclear fuel waste;
- low-level and intermediate-level waste;
- waste from uranium ore extraction and concentration.

The first category concerns the fuel assemblies of the various CANDU-type reactors. The second category concerns common waste resulting from operation and dismantling of facilities and legacy waste resulting from past activities, for example the Port Hope radium refinery. Finally, Canada lists the residue from uranium processing on currently operating, inactive or decommissioned sites.

The low-level radioactive waste management Office compiles the inventory. That Office, which is also responsible for current and legacy waste management programmes, is administered by the AECL research organisation (Atomic Energy of Canada Limited) on behalf of the Ministry of natural resources.

Three inventories are currently available, published in 1999, 2004 and the most recent in 2009.

History

Canada has produced radioactive waste since the 1930s, when the first uranium mine came into operation at Port Radium, in the North-West Territories. The radium was refined for medical purposes, and later uranium was processed at Port Hope, in Ontario. Research and development activities on use of nuclear power for production of electricity started in the 1940s, at the Chalk River Laboratories (CRL) of Atomic Energy of Canada Limited (AECL).

Today the radioactive waste generated in Canada comes from: uranium mines and concentration plants, uranium refineries and uranium conversion plants, manufacturing of nuclear fuel and operation of nuclear reactors for electricity generation, nuclear research and radio-isotopes production and use.

Appendices

Drawing up the *National Inventory*

Methodology

Appendix 1

1.1 Organisation selected for surveying radioactive materials and waste

1.1.1 Legislative context

Article L. 542-12 of the French Environment 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 their location on the national territory."

The role of the Agency is to inform the public on the type and location of radioactive waste. The "Council of State" Order 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 mandatory declarations.

The *National Inventory* also contains the information on storage facilities for waste requested by the French National Radioactive Materials and Waste Management Plan (PNGMDR) [III].

For the 2012 issue of the *National Inventory*, stocks of existing waste were established at the end of 2010, and forecasts were established up to 2020 and 2030 in accordance with the dates defined by the Ministerial Order of 3 February 2011 [IV].

1.1.2 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 of each producer or holder in France. Andra has performed this survey since 1992. Originally based on voluntary declarations by the waste producers and holder, for the last 5 years this activity has been performed within the regulatory framework described in the *previous paragraph*;

• to provide an overview of present and future waste volumes, based on projected scenarios with snapshots of stocks on the key dates defined in the Ministerial Order.

Note that only the waste corresponding to existing or licensed operations and dismantling of installations at the end of 2010 is assessed in the *National Inventory*.

[I] *Order 2008-875 of 29 August 2008 which implements Article 22 of Planning Act 2006-739 of 28 June 2006, relating to sustainable management of radioactive materials and waste.*

[II] *Order of 9 October 2008 relating to the nature of information that the managers of nuclear activities and companies mentioned in Article L. 1333-10 of the Public Health Code are obliged to establish, update and periodically transmit to the National Agency for the Management of Radioactive Waste.*

[III] *Order 2012-542 of 23 April 2012, which implements Article L. 542-1-2 of the Environment Code and establishes the requirements in relation to the National Plan for the Management of Radioactive Materials and Waste.*

[IV] *Order of 3 February, 2011 relating to information to be transmitted to the National Agency for the Management of Radioactive Materials and Waste in view of the 2012 issue of the National Inventory of Radioactive Materials and Waste.*

Five guiding principles govern the production of the *National Inventory* and 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 plan for the management of radioactive materials and waste (PNGMDR) 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 radioactivity properties for industrial, Defence and medical purposes. The aim is to present a 'snapshot' of all the waste located in France at a given time, regardless of its physical or chemical state, conditioned or not, liquid or solid and of high or low activity level. The scope of the survey is not restricted to waste disposal and storage facilities. It also covers all installations that contain waste, even temporarily, awaiting collection by Andra, for example in medical research or university laboratories. It also encompasses radioactive materials. The 2012 issue also looks at polluted sites.

Appendix
1

Neutrality

The *National Inventory* provides a transcript of the collected data in a factual way, without pronouncing judgement on the potentially hazardous nature of the situations and management modes described.

Transparency

The *National Inventory* provides an overview of radioactive materials, regardless of their origin. This approach is meant to complement the efforts made to work transparently, a principle to which the public authorities, waste producers and the Nuclear safety authority have been committed for several years [V].

To observe this principle of transparency, a steering committee chaired by the Chief Executive Officer of Andra and made up of members from outside the Agency, oversees preparation of this Inventory.

The *National Inventory* steering committee

This committee validates the overall consistency of the volumes of existing and future waste and materials published in the *National Inventory* as well as the assumptions made in the projected scenarios (the main difficulty here is linked to the possible changes in the strategy adopted by the various parties involved and to the review of the related technical documentation). The interpretation of data in the National inventory is validated by the steering committee. It is made up of:

- Representatives of the government bodies concerned (Ministry for the environment and Ministry for energy);
- a representative of the Nuclear safety authority (ASN);
- representatives of the main waste producers (both inside and outside the nuclear power sector);
- a representative of the Parliamentary Office for the evaluation of scientific and technological choices (OPECST) in an observer capacity;
- a representative of the National Evaluation Board (CNE, *see Chapter 1*), in an observer capacity;
- representatives of the Environmental organisations and Local Information Commissions;
- a representative of the High Committee for transparency and information on nuclear safety (HCTISN).

[V] *Act 2006-686 of 13 June 2006 relating to nuclear transparency and safety.*

Responsibility of the parties for their declarations and verification of management solutions by Andra

The National Inventory presents the data declared by the 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, as described on *page 175*, entitle it, if necessary, to inform the appropriate authorities should a waste producer fail to fulfil its obligations regarding declarations. Furthermore, under Article 2 of the Order of 23 April 2012 relative to PNGMDR requirements, Andra checks whether the waste management solution proposed by the producer is suitable. The producer's or waste holder's obligation to declare does not, however, dispense with the Agency checking the comprehensiveness of its survey by gathering information from various sources. When the presence of radioactive waste is found on sites not yet surveyed, it is integrated in the *National Inventory* when it is next updated.

1.2 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 Environment Code. The information it gathers is correlated with the various other sources to which it has access. This set of information is presented in three catalogues:

- **this synthesis report;**

- **the Geographical Inventory** which presents the sites producing, treating, conditioning, storing and disposing of radioactive waste. It also presents the legacy mining sites on which residues from uranium ore processing are definitively disposed *in situ*, the legacy disposal facilities and sites polluted by radioactivity, that have been or are being cleaned up, or have been confirmed, and on which waste is stored;

- **the Catalogue of families** which presents the waste survey data grouped into families. Each waste family is made up of waste incorporating similar characteristics with respect to the criteria chosen for each group. This classification is mainly used for forecasting purposes.

1.2.1 The Geographical Inventory

The Geographical Inventory presents the sites that produce, treat, condition and store radioactive waste, operated by the waste producers and holders. It also lists the Andra disposal facilities, National Defence establishments, 'small-scale nuclear activities' waste producer sites and legacy sites. These legacy sites include mining sites, legacy disposal facilities and sites found to be polluted, mostly those related to the use of radium.

The information is factually recorded for each region, in statement tables for the 'small-scale nuclear activities' waste producers and Defence establishments excluding INBS, and in geographical data sheets for the other declarers. These tables or figures provide information on the radionuclides used and the volume of waste (when this information is available); the management solutions are specified. Depending on its size, a site may give rise to one or several geographical data sheets. The most detailed geographical data sheets present the inventories of the largest producers, such as EDF, AREVA and the CEA, for example.

The waste category, as defined in *chapter 1*, is detailed, as well as the family to which it belongs (described in the Catalogue of families). Each type of waste present on the site is mentioned, associated with its level of activity and the volume of that waste once conditioned. The Synthesis report uses and analyses the data from the Geographical Inventory.

Sites contaminated by radioactivity

These sites are identified through the risk studies carried out on former industrial sites or past enquiries on some more or less abandoned industrial activities.

Furthermore, within the framework of the Inter-ministerial circular of 17 November 2008 regarding the general interest missions entrusted to Andra, the Regional Directorates for industry, research and the environment (DREAL) and the National safety authority (ASN) may also bring to Andra's attention information that may complete or provide more details on polluted sites.

Once 'confirmed' *(see chapter 4)*, Andra takes responsibility for remediation of these sites within the framework of its general interest mission. These sites are then listed on data sheets in the Geographical Inventory.

It should be noted that, in the special case of contaminated sites, the party making the declaration is not always a clearly identified industrial firm; the declaration is often made by an individual person, a local authority or an asset liquidation management company 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 public interest activities.

Thus, it is often the Agency that makes the declaration. The data sheets related to these confirmed contaminated sites present a brief history of the site and its status (remediated, being remediated or pending remediation).

The sites that were declared remediated at the end of 2007 in the 2009 issue of the *National Inventory* no longer appear in the 2012 issue.

Appendix 1

Defence sector centres

This activity sector covers professional activities relating to National Defence, directly attached to the Ministry for defence or to the armed forces.

All the armed forces have equipment that draws on the properties of radioactivity, especially for night vision.

Equipment that is worn or has become obsolete is waste, and it is listed for each National Defence establishment.

This equipment is generally small, such as radium or tritium compasses, sights, luminescent plates and dials, together with various monitoring devices.

Some aircraft engine parts that have been withdrawn from service and contain thorium are also listed (magnesium/thorium alloy housing, for example).

1.2.2 The Catalogue describing the families of radioactive waste

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 forecasting purposes the waste has been assigned to families. The detailed description of each family in the *National Inventory* is the subject of the Catalogue of families.

Each waste family is made up of waste incorporating similar characteristics with respect to the criteria chosen for each group.

The 2012 edition 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;
- the industrial activity responsible for producing the waste package;
- the nature and physical and chemical characteristics of the raw waste prior to conditioning: fission products and minor actinides, fuel assembly structures (hulls, end caps), water purification resins, sludge or concentrates, solid waste from maintenance operations, etc.

- the production status of the raw waste and package; there are two possibilities for waste and also packages:
  - waste which production is finished, waste which is being produced, waste which production 'has not yet started',
  - package which production is finished, package which is being produced, package which production 'has not yet started',
- the actual or planned conditioning mode, in particular the material used to make the matrix and container.

The waste volumes given in the *National Inventory* are expressed in 'cu. m conditioned equivalent'. This unit is used to prepare the statements. It allows the waste to be accounted for using a single, common unit. Forecast quantities are also expressed using this unit.

The waste activity levels have been calculated by Andra for each family, using the characteristics of the package given by the radioactive waste producers and holders *(see appendix 3)*.

The total activity of the waste and also the activity per gram of package are calculated at the date of the inventory (end of December 2010) in becquerels and becquerels per package gram.

Radioactive waste production forecast

As previously indicated, operating waste from existing or licensed installations, waste that will be subject to recovering and conditioning (RCD) and waste from decommissioning of facilities at 31 December 2010 is listed in the *National Inventory*.

In the case of radioactive waste production forecasts, it is essential to firstly define the production scenarios for the nuclear power sector. The type and volume of radioactive waste produced by the nuclear power industry cannot be forecast without making assumptions as to future electricity consumption, the future of nuclear power plants and the spent fuel treatment policy, etc. The assumptions taken into account to assess waste volumes over time differ according to these scenarios.

The radioactive waste production forecasts have been made up to the milestone dates stipulated by Order [VI]: 2020 and 2030. The assumptions considered in building this scenario are described in *Chapter 2*.

Since the *National Inventory* accounts for all the waste, whether conditioned or unconditioned, assumptions regarding conditioning modes are also needed to quantify forecasts.

The conditioned equivalent waste volume forecasts are presented by family.
The materials and waste products are highly dependent on future political and energy choices.

Appendix
1

[VI] *Order of 3 February 2011 relating to information to be transmitted to the National Agency for the Management of Radioactive Waste in view of the 2012 issue of the National Inventory of Radioactive Materials and Waste.*

In particular, these choices will affect how nuclear power plants licences may be extended and/or how the current operating fleet is to 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 on the back end of the nuclear fuel cycle.

The scenario adopted in the 2012 edition to assess the waste by family in 2020 and in 2030 is a scenario that assumes continuing operation of nuclear power plants, with a plant service life of 50 years. 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 and Defence.

Beyond 2030, the 2012 edition of the *National Inventory*, like its predecessors, includes an estimation of the total quantity of waste produced by existing facilities until the end of their operation life, including waste generated by dismantling operations *(see Chapter 2)*. 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 *National Inventory* has therefore produced estimations based on two types of scenarios:

- phasing-out of nuclear power with an operating life of 40 years so the fleet is not to be renewed;
- complete renewal of the nuclear power plants, with an operating life of 50 years.

These are only two of the many possible scenarios within other ones.

These evaluations should therefore only be considered as approximate indications. The estimations and the scenarios that underpin them are presented in *chapter 2*.

1.2.3 Survey of radioactive materials

In accordance with article L. 542-12 of the Environment Code, as amended by the Act of 28 June 2006, the *National Inventory* provides a survey of radioactive material.

Each operator tracks the masses of these nuclear materials as part of the 'nuclear material accounting' process: this is regularly monitored 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.

Is the *National Inventory* really comprehensive?

Successive updates since 1993 have brought fuller and more detailed knowledge concerning the location of waste and some of its characteristics, as the producers themselves learn more about their waste products.

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

A producer may overlook some waste when making a declaration. However, as the major producers also declare their waste stocks to the Nuclear safety authority, there is little risk that anything will be omitted. These 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 licensed by its customers.

From one edition to the next, some facilities may no longer be included in the survey because they no longer contain radioactive waste (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*. Furthermore, in response to the incidents that occurred at the Tricastin site (Drôme district) in the summer of 2008, the Ministry for Ecology, Energy, Sustainable Development and Territorial Planning asked the High Committee for transparency and information on nuclear safety (HCTISN) to make the necessary recommendations. As a result, more detailed information concerning certain legacy sites has been provided in the *National Inventory*. .../...

On the night of 7 to 8 July, 2008, during transfer operations, approximately 20 cu. m of uranium-contaminated effluent was spilt into the environment by SOCATRI (Tricastin nuclear site - Drôme district), which discharged approximately 70 kg of non-enriched uranium into the 'Gaffière' river.

This incident led to the authorities taking temporary precautionary measures to restrict the use and consumption of water, prohibit fishing in the surrounding rivers and prohibit swimming in the nearby lakes.

The Ministry for Ecology, Energy, Sustainable Development and Territorial Planning then asked the High Committee for transparency and information on nuclear safety (HCTISN) for its opinion on the consequences of this incident and its follow-up at local level.

Additionally, the Minister himself extended his request for advice on the radiological monitoring of all nuclear sites and on management of legacy radioactive waste storage sites [VII].

Appendix
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[VII] *«Opinion on radiological monitoring of water in the vicinity of nuclear facilities and on management of former radioactive waste disposal sites – 18 recommendations for improving information, transparency and consultation with stakeholders...» which can be consulted online at www.developpement-durable.gouv.fr or www.hctisn.fr*

...Notwithstanding the above, there are certainly some potential holders of radioactive waste that have never approached Andra, or radioactively contaminated sites that remain to be identified.

For contaminated sites, historical surveys are conducted to identify potentially contaminated sites that have been forgotten over time. Among the recommendations made by the High Committee for transparency and information on nuclear safety in answer to the Minister's request [VII], recommendation 15 states that: "The High Committee recommends that the BASIAS site developed by the Ministry for Ecology in connection with the 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.

It remains very difficult, however, to guarantee the thoroughness of the survey for some activity sectors mentioned on *page 178* (hospitals, research laboratories other than those of the CEA, etc.), both in terms of waste location and also as to whether waste is actually to be found on the listed sites.

Finally, 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.

1.3
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 activities' radioactive waste producers.

The online survey is now available to all producers.

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

Once the data have been checked by Andra, they are entered in a computerised database. This base is used to prepare reports.

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

1.3.1
Verifying the data on stocks at the end of 2010

Declarations are submitted by various types of producer.

The data verification procedures depend on the type of producer:

- **major players in the nuclear industry** (EDF, AREVA, CEA) managing several sites.

Each site appoints 'officers' who are well acquainted with the state of stocks and who complete the declaration forms (the declarant). The declarations are then checked and validated by a responsible person from each organisation (producer validator).

The reliability of declarations relies on the producer's internal monitoring systems: verification and validation systems and re-reading for consistency.

- **the 'small-scale nuclear activities' radioactive waste producers** do produce less radioactive waste. In many cases, these firms already have arrangements with Andra for their waste removal. The Agency is in direct contact with appointed officers on each site;

- **waste storage and disposal facilities** are mostly basic nuclear installations (INB or INBS) or facilities classified for environmental protection (ICPE). 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;

- **in the case of sites contaminated by radioactivity,** knowledge of the sites for which Andra is responsible for their remediation allow for the most possible reliable declarations.

For other sites, the Agency contacts the site owner or organisation responsible for the clean-up.

Andra checks each detail in the declaration: comparing with the previous declaration, checking for consistency, cross-checking with any other available sources of information and examining the management solution that the producer has chosen for the waste, etc.

The management solution proposed in the *National Inventory* does not presuppose acceptance of the waste in the corresponding disposal facility.

If, after their analyses, the declarations need to be corrected in any way, Andra contacts the producer, and then validates the corrected data.

The data is then compiled in a statement report submitted to the *National Inventory* steering committee which confirms the overall consistency of volumes related to materials and waste.

Appendix
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1.3.2
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, strictly speaking, be 'verified'.

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.

1.3.3
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.

The data come from the producers' technical documentation or package inspections performed by Andra on the industrial sites, or other information available to Andra.

They have been re-read by the producers concerned. The data are illustrative and intended to give the reader a good overview of the main characteristics of the waste.

They are likely to be changed or updated with each new edition of the *National Inventory*.

Management of French and foreign radioactive waste from spent fuel in the AREVA facilities at La Hague

Appendix 2

2.1
Foreign spent fuel processing at the La Hague site

Since it was commissioned in 1966, the first spent fuel treatment plant at the La Hague site, UP2-400, has processed approximately 5,000 tonnes of spent fuel from the French GCRs (natural-uranium gas-cooled reactors in the Chinon (Indre-et-Loire district), Saint-Laurent-des-Eaux (Loir-et-Cher district) and Bugey (Ain district)) power plants. The UP1 plant at the Marcoule site (Gard district) (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 UP2-400 plant was modified accordingly (the so-called HAO worshops in particular) and its capacity (of around 400 tonnes/year of water reactor fuel) became sufficient to propose spent fuel processing services to foreign customers, with the first contracts signed in the 1970s.

With the commissioning of UP3-A (1990) and UP2-800 (1994), more than 26,000 tonnes of light water reactor spent fuel had been processed at the La Hague site at the end of 2010, including approximately 61% for France, 21% for German customers, 11% for Japanese customers and the rest for Belgian, Swiss, Dutch and Italian 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 were processed 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 first act has set up the legal framework concerning processing of foreign spent fuel in France, prohibiting disposal of waste originating from spent fuel, in France [I].

Article L. 542-2 of the Environment 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 signature of intergovernmental agreements published in the Official Journal of the French Republic, which specifies forecast periods for receipt and processing of these substances.

This article also requires spent fuel processing facility operators to submit a report (made public on the Internet) to the Minister for energy 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, as well as all resulting processing waste and the forecasts relating to the processing operations.

[I] *Act 1381 of 30 December 1991 relating to research on radioactive waste management, called the Bataille Act.*

[II] *Planning Act 2006-739 of 28 June 2006, relating to sustainable management of radioactive materials and waste. The provisions of this Act have been consolidated in the Environment Code.*

Under the provisions of the Act of 28 June 2006 (consolidated in Articles L. 542-2 and L. 542-2-1 of the Environment Code) and Order 2008-209 of 3 March 2008 [III], AREVA has set up an inventory and shipment management system for waste resulting from processing of foreign spent fuel in the basic nuclear installations (INB) at the La Hague site (Manche district), approved by the Order of 2 October 2008 [IV]. This is the EXPER (standing for residue shipment in French) system, intended to ensure "distribution of processing waste according to two types; waste to be shipped abroad and waste requiring long-term management on French territory and allocation of the corresponding share to each party concerned" [III]. The distribution principles set out in Decree 2008-209 are discussed in *section 3* of this appendix.

2.2 Conditioning of final radioactive waste from spent fuel processing

The **spent fuel processing operations** at the La Hague site (Manche district) consist in **separating**, on one hand, **the recoverable materials** (uranium et plutonium) and, on the other, **the final radioactive waste** (fission products, minor actinides and cladding waste) containing most of the spent fuel radioactivity.

The 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, called residue by AREVA, for storage and transport according to the 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 (Manche district) is divided into two categories:

- **Fission products and minor actinides** generated by combustion in a reactor 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 a CSD-V package (standard vitrified waste container) to form vitrified waste packages. As a result, nearly all the activity contained in the ultimate waste is conditioned in a compact, lasting, confined manner. All ultimate waste is classified as high-level waste (HLW);
- **Cladding waste** is composed of metallic components (cladding hulls, plates) used to secure and confine the fuel, including associated assembly parts (spacer grids, end caps). This waste is compacted and conditioned in CSD-C containers at the La Hague plant (standard compacted waste containers) 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 the foreign owners in these two types of waste package." [IV]

Appendix
2

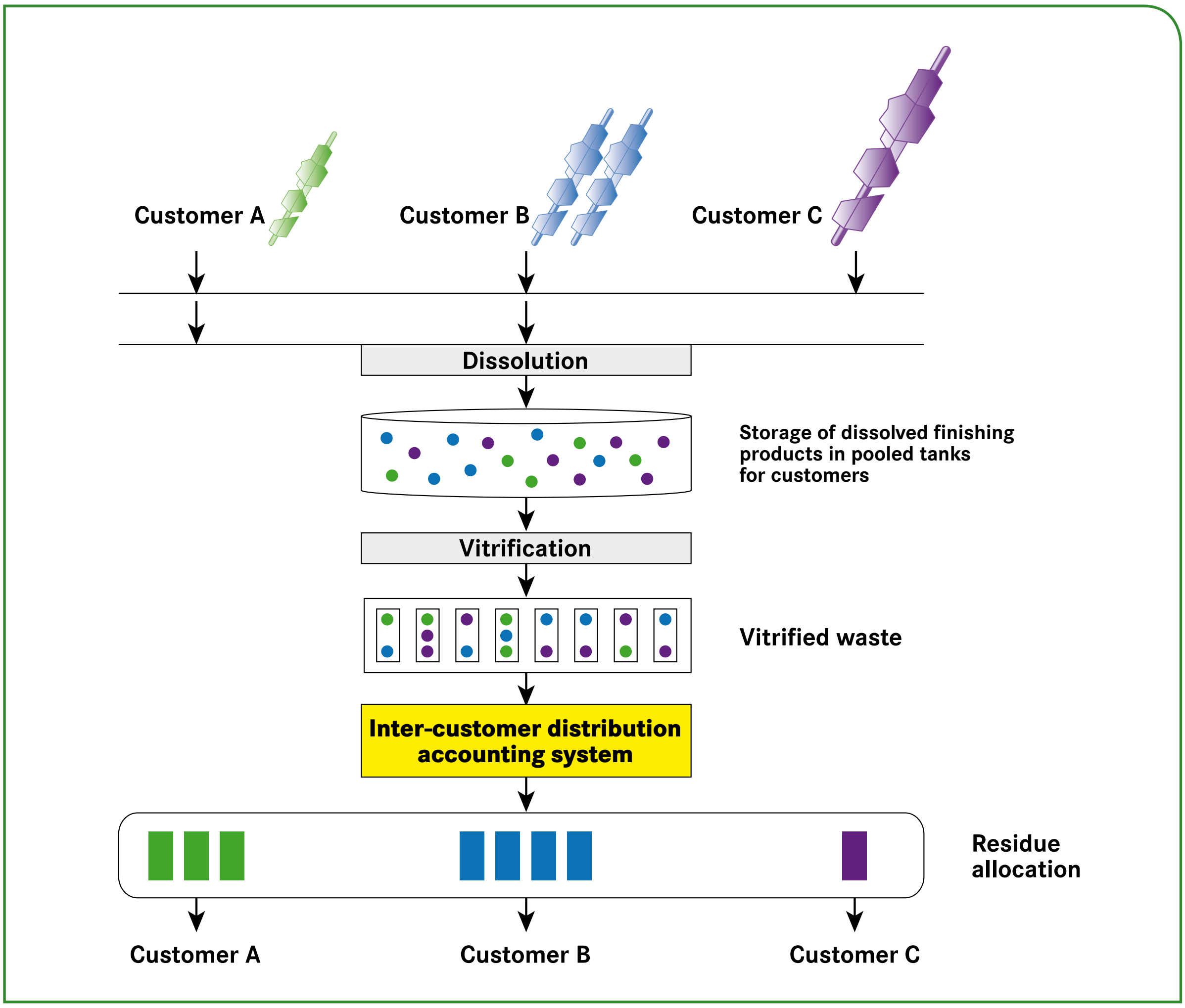
[III] *Order 2008-209 of 3 March 2008 relating to the applicable procedures for processing of spent fuel and radioactive waste from abroad.*

[IV] *Order of 2 October 2008 on approval of the inventory and shipment management system for waste resulting from processing of foreign spent fuel in the basic nuclear installations (INB) at the La Hague site.*

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 below* illustrates the principle of waste package allocation and illustrates the case of pooled fission and minor actinide product management.

Residue (waste packages) allocation system to AREVA La Hague (Manche district) customers: vitrified waste package



2.3 Allocation management system implemented at the La Hague site: EXPER

As previously explained, AREVA has implemented the **EXPER system** within the framework of existing legal and regulatory provisions [V].

The Order of October 2008 defines the system as follows: "It is exclusively devoted to spent fuel processing. It serves the following purposes:

- **managing allocation** of conditioned waste packages to customers;

- **monitoring completed and forecast schedules**, from spent fuel receipt and processing to waste package shipment.

This system replaces the waste activity unit system ('UR' 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."

2.3.1 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:

- **the radioactivity to be shipped to each owner.** This is expressed in waste activity units (UARs) and corresponds to the quantity of neodymium contained in the ultimate waste (neodymium is a fission product chosen because it is a representative indicator of overall activity content and can be accurately measured);

- **mass to be shipped,** expressed in waste mass units (UMRs) 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." [V]

Appendix 2

[V] *Order of 2 October 2008 on approval of the inventory and shipment management system for waste resulting from processing of foreign spent fuel in the basic nuclear installations (INB) at the La Hague site.*

Planning Act 2006-739 of 28 June 2006, relating to sustainable management of radioactive materials and waste. The provisions of this Act have been consolidated in the Environment Code.

Order 2008-209 of 3 March 2008 relating to the applicable procedures for processing of spent fuel and radioactive waste from abroad.

Article 3 of the Order 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 must 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 must indicate waste quantities and physical characteristics according to the origin. It must maintain an inventory of processed waste and manage its allocation to recipients.

It must record dates on which waste is received in France, waste processing periods, and dates of waste shipment abroad. It must be consistent with the conditions of application of each intergovernmental agreement."

2.3.2 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 (UAR) and waste mass units (UMR) inventoried. The general rule is based on the interchange ability 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 (UAR) or waste mass units (UMR) is stipulated at the end of the contract (...)." [IV]

2.3.3 Customer account management

The Order of 2 October 2008 [IV] stipulates the following: "AREVA must manage 'accounts' for all customers of the La Hague (Manche district) processing plant, to which waste activity and waste mass units are to be allocated for each customer.

These accounts will be credited or debited during the various phases of spent fuel processing.

A customer's account will 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 will be debited from the customer's account."

[III] *Order 2008-209 of 3 March, 2008 relating to the applicable procedures for processing of spent fuel and radioactive waste from abroad.*

[IV] *Order of 2 October 2008 on approval of the inventory and shipment management system for waste resulting from processing of foreign spent fuel in the basic nuclear installations (INB) at the La Hague site.*

2.4
Shipment to foreign customers

2.4.1
Waste covered in Article L. 542-2-1 of the Environment Code

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.

Return of vitrified waste to Japan

CSD-V package

CSD-V packages

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.

At 31 December 2010, most of the foreign CSD-V packages (88.7% i.e. 4,780 CSD-Vs) had been shipped; whereas, as is presented in *table page 195*, the vast majority of CSD-V produced and present on the La Hague (Manche district) site concerns France (94.1%).

Appendix
2

[IV] *Order of 2 October 2008 on approval of the inventory and shipment management system for waste resulting from processing of foreign spent fuel in the basic nuclear installations (INB) at the La Hague site (Manche district).*

TN28 casks used to transport CSD-V packages to Belgium, the Netherlands and Japan

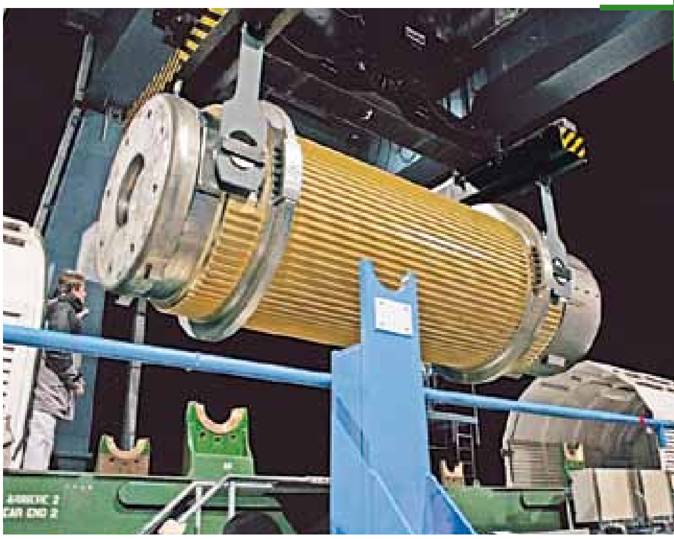
Foreign customers currently store the delivered CSD-Vs:

- either in shafts, in facilities similar to those at La Hague (Rokkasho-Mura in Japan, Mol in Belgium, HABOG in the Netherlands, the Almacen Temporal Centralisado or ATC project in Spain);
- or in transport and storage casks (Gorleben in Germany, Zwilag in Switzerland).

HABOG high-level vitrified waste storage facility (Hoogradioactief Afval Behandelings en OpslagGebouw) in the Netherlands

CSD-C packages

By 31 December 2010, 292 CSD-Cs had been shipped. Estimated shares corresponding to French owners and foreign customers are shown in the *table on the next page*.



TN 81 casks used to transport CSD-C packages

Cross-section of a CSD-C package

There are more CSD-C packages remaining to be shipped than CSD-V packages, since AREVA has given priority to shipment of radioactivity units, rather than mass units.

By 31 December, 2010, 10 828 CSD-V and 10 270 CSD-C packages were present in the basic nuclear installations operated by AREVA NC at La Hague (Manche district). The share of radioactive waste per country is given in the *table below*.

Assessment of the share of CSD-V and CSD-V packages to return to each country
(concerns packages stored on 31 December 2010)

Radioactive waste on the AREVA NC site LA HAGUE (Manche district) on 31 December 2010			
		Share per country by %	
		CSD-V	**CSD-C**
France		94.1	52.1
Germany		2.7	27.8
Australia		< 0.1	0
Belgium		0	2.6
Spain		0.6	– [1]
Italy		0.6	1.5
Japan		0	12.5
Netherlands		< 0.1	0.8
Switzerland		2.0	2.7
Total		**100**	**100**

[1] *Currently, Spain is not concerned by the shipment of CSD-C type structure waste. Spanish shipments concern packages conditioning effluent activity and cement containers that are described in the Waste family catalogue.*

The activity of radioactive waste

Appendix
3

How is the activity of waste measured?

It is essential to know the radioactivity level of waste to categorise it and select its final solution.

The activity of a radioactive substance is the number of its atoms that spontaneously decay per unit of time. **This activity diminishes over time.**

Each decay is accompanied by the emission of radiation (gamma) or particles (alpha, beta, or neutron). As their energy is representative of the nucleus that has decayed, measurement of this radiation (intensity and energy) by appropriate and correctly calibrated instruments enables us to assess the activity of the waste and quantify the different nuclides.

Measurements are performed by spectrometry on the package and/or on samples.

However, some radionuclides are difficult to measure due to their low quantity and/or the low energy of their radiation. Correlation factors (scaling factors) are therefore established between the activity of these radionuclides and that of a more easily measurable radionuclide used as a tracer.

This enables the distribution of activity from the different radionuclides in the waste (radiological spectrum) to be assessed.

Most often, the producer assesses the activity of the waste when it is produced or conditioned. For reasons of simplicity, it is this activity, assessed at the date of production that is declared by the producers.

The declaration of activity does not therefore take the natural decay of the radionuclides into account.

To present homogeneous data in the Catalogue of families, Andra indicates an activity value per family, at the end of 2010, which it has calculated using the available data.

The calculation is based on 144 radionuclides with half-lives greater than 6 months, and includes the radioactive decay since the waste production date. These figures are therefore not directly comparable with the values declared by the producers.

The calculation method used by Andra is set out below. For clarity, it is applied to an actual HLW package.

Activity calculation: AREVA CSD-V vitrified waste package at the La Hague site

This family (F1-3-01) concerns the AREVA CSD-V vitrified waste packages at the La Hague site (Manche district).

At the end of 2010, 10,828 packages of this family of waste had been produced.

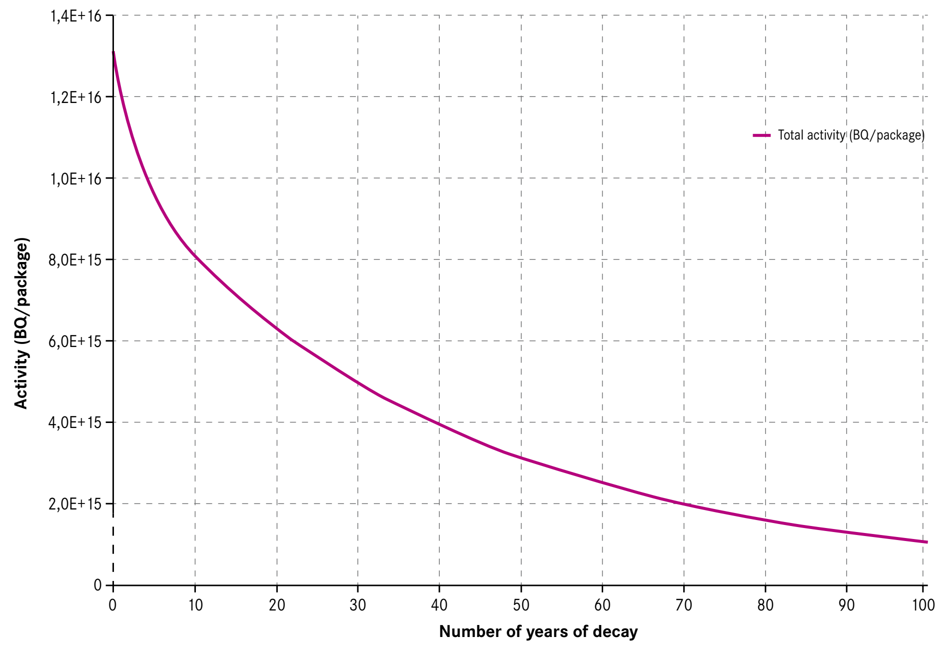
The radiological activity declared by the producer, relating to these packages, is 173 exabecquerels (173.10^{18} Bq).

It corresponds to the activity assessed during production of the packages.

These packages have been produced since 1989, the date on which the R7 workshop of the La Hague plant was commissioned.

The activity of each package decays regularly from its time of production. For example, the activity of the first packages produced has decayed over 21 years, from their production in 1989 up to the end of 2010, whereas the activity of the packages produced in 2009 has only decayed over one year *(see below)*.

Taking the decay and the number of packages produced each year since 1989 into account, Andra has calculated the total activity of this family to be 100 exabecquerels.



Appendix
3

Radioactive decay of long-term waste

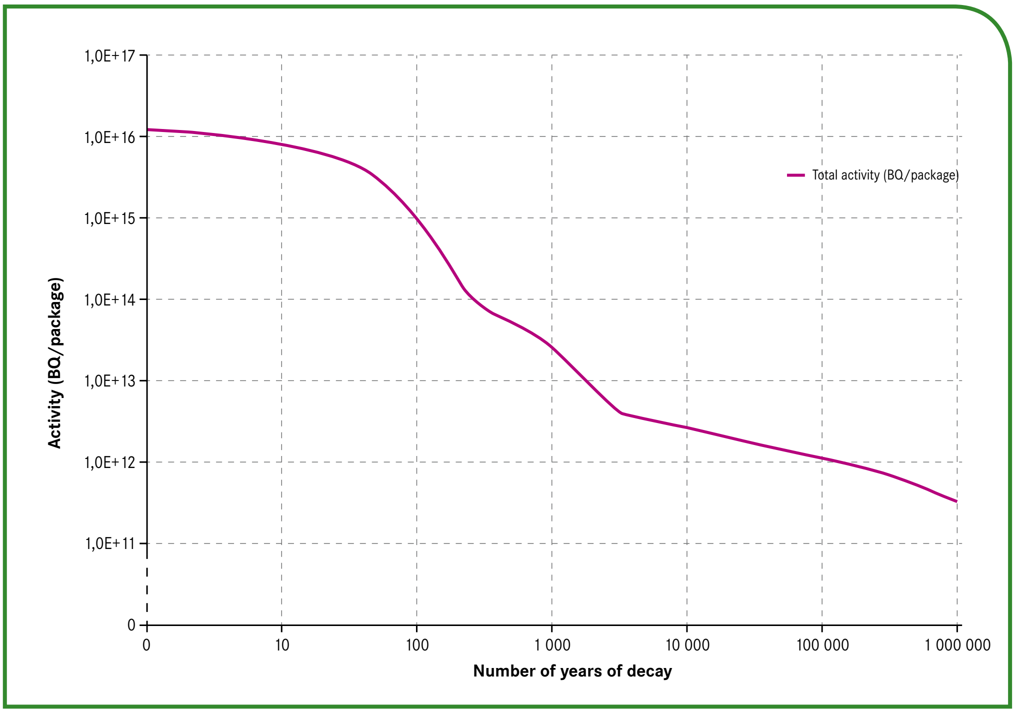
The total radioactivity of waste packages decreases according to the half-life of each of the radionuclides comprising it. At the end of several centuries, only the 'long-lived' component, i.e. the one with radionuclides with a half-life greater than several decades remains.

The following curve illustrates the change in the total radioactivity over one million years for the average spectrum of the F1-3-01 family (CSD-V package).

The initial decay is dominated by that of caesium-137 and strontium-90, which are short-lived elements.

After 1,000 years, the activity has reduced by a factor of approximately 800. Radionuclide decay leads to reduction of the package's thermal power, i.e. the heat that it emits.

This changes from 2 kW on average per package when manufactured to 0.6 kW after some fifty years, and to around 0.001 kW after 10,000 years.



Glossary

Glossary

A

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).

Activity

Number of nuclear isomeric decays or transitions produced per time unit in a radioactive substance. The unit of activity is the becquerel.

B

Back end of fuel cycle

Nuclear fuel cycle operations after use in the reactor, from spent fuel processing to radioactive waste disposal.

Baddeleyite

Rare natural ore of zirconium oxide (ZrO_2).

Basic clothing

Basic protective clothing is mandatory for French nuclear operators, which is worn instead of regular clothing in controlled areas.
It includes:
- a tee-shirt;
- a pair of slippers;
- an overall.

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, 10^{15} Bq) or exabecquerel (EBq, one billion billion, 10^{18} Bq).

Bituminised sludge

Sludge resulting from co-precipitation operations in liquid radioactive effluent treatment plants and conditioned in bitumen.

Burnup rate

Total energy released per unit mass of a nuclear fuel.
It is currently expressed as gigawatts-day per tonne of heavy metal (GWd/t).

C

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

Unit used to prepare the statement reports. It allows the waste to be accounted for using a single, common unit. Forecasts also use the unit of 'conditioned equivalent volume'.
For waste for which the conditioning is not yet known, assumptions are performed to assess the conditioned equivalent volume.

Conditioning matrix

Solid material used to immobilise or confine radioactive waste, or simply to improve the mechanical crushing resistance of waste packages.

Confinement (of radioactive materials)

Holding radioactive waste, using a set of devices (barriers) aimed at preventing the dispersal of unacceptable quantities of radioactive material outside this predetermined area.

Container

In the nuclear industry, a term referring to a handleable sealed vessel used for transport, storage or disposal operations.

Contamination (radioactive)

Unwanted presence of significant quantities of radioactive substances on the surface or within any environment.

D

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 final decommissioning order.

Disposal package

Additional container into which one or several radioactive waste packages may be placed with the aim of disposal in a specific facility. This additional conditioning is required for handling, safety and reversibility functions.

E

Enriched recycled uranium (ERU)

Enriched uranium obtained through enrichment during spent fuel processing. The term enriched reprocessed uranium is also used.

F

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.

G

Glossary

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, 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

Nuclides resulting from the fission of a fissile element (nucleus): each nucleus of fissile material subject to nuclear fission splits into two (exceptionally three) parts, which stabilise as new atoms. When leaving the nuclear reactor, most of these fission products (approx. 95% by mass) are stable (approx. 85%) or have short-lived radioactivity (approx. 10%). A few (approx. 5%), for example ^{99}Tc or ^{129}I have long-lived radioactivity.

Front end of fuel cycle

Nuclear fuel cycle operations from mining to fuel fabrication.

Fuel (nuclear)

Substance containing nuclides that are consumed by fission in a nuclear reactor to sustain a nuclear chain reaction.

Fuel assembly

Group of fuel elements that remain attached to each other, particularly during reactor core refuelling operations.

Fuel rod

Small diameter tube, sealed at both ends, containing fuel pellets.

G

Gas-cooled graphite-moderated reactor (GCR)

Generation 1 nuclear fission reactor using graphite as moderator and carbon dioxide gas as coolant.

Glove box

A glove box is a confinement completely isolating a process by a transparent wall (special material that filters a part of the radiation). Gloves are installed in the wall to allow completely safe handling of radioactive materials. The device generally includes ventilation that keeps the box at a negative pressure in relation to the exterior, which confines the radioactive materials inside.

Graphite waste

Term used in France for a radioactive waste category comprising graphite from old gas-cooled graphite-moderated reactor cores (approx. 20,000 tonnes). This graphite contains tritium and long-lived elements (carbon-14, chlorine-36).

H

Heavy metal (HMt)

In practice, this expression mainly concerns uranium and plutonium: the quantity corresponds to a tonne of uranium or plutonium contained in the fuel prior to irradiation.

High level

High level waste mainly comes from spent fuel after processing. The activity level of this waste is around several billion becquerels per gram.

Hulls and end caps

Radioactive waste comprising fuel assembly hulls and end caps once the rods have been sheared up and the fuel has been chemically dissolved.

I

ILW-LL

Intermediate-level long-lived waste mainly comes from spent fuel processing. The activity of this waste is from around one million to one billion becquerels per gram.

Industrial volume

This volume corresponds to the volume of water displaced by submersion of a waste package.

ISD

Conventional waste disposal facility

Isotope

1. Any nuclide of a given element.
2. All the nuclides of a single element.

L

LILW-SL

Low- and intermediate-level short-lived waste mainly comes from the operation and dismantling of nuclear facilities, fuel cycle installations, research centres, and a very small part from biomedical research activities. The activity level of this waste is generally in the range of a few hundred to one million becquerels per gram.

LLW-LL

Low-level long-lived waste comes from dismantling the first generation natural-uranium gas-cooled reactors and from radium bearing waste. Graphite waste has an activity level of between ten thousand and a few hundred thousand becquerels per gram. Radium-bearing waste has an activity level between a few tens of becquerels per gram and a few thousand becquerels per gram.

Glossary

Long-lived waste

Radioactive waste in which the main radioactive components are radionuclides with a radioactive half-life greater than 31 years.

M

'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.

Moderator

Material made of light nuclei which slow down neutrons by elastic diffusion. They are used in slow neutron nuclear reactors to increase the probability of neutron interaction with the heavy nuclei of the fuel. The moderator should not capture neutrons, causing them to be 'wasted', and be sufficiently dense to ensure effective slowing down.

MOX fuel

Abbreviation for mixed-oxide fuel made of plutonium and uranium.

N

Nuclear fission

Disintegration of a heavy nucleus, generally by splitting into two nuclei with atomic masses ranging from 70 to 170.

Nuclide

Nuclear species characterised by its atomic number Z and its mass number A, equal to the 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. $^{238}_{92}U$.

P

Plutonium

Element with atomic number Z = 94. It was initially produced for defence applications. Generated in nuclear reactors by uranium-238 irradiation, it is currently used as a MOX fuel component in certain light-water reactors. It is also the fuel considered 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.

Pollution

Direct or indirect introduction, by human activity, of radioactive substances into the environment likely to contribute to or cause a danger to human health, deterioration of biological resources, ecosystems or property, interfering with the legitimate use of the environment.
- legacy pollution is pollution resulting from former human activity.
- residual pollution concerns a quantity or concentration of pollutants remaining in a given environment after remediation.

Pressurised water reactor (PWR)

Thermal neutron reactor using light water as moderator and coolant. This water is maintained in liquid state inside the reactor core through pressure high enough to prevent bulk boiling at the operating temperature.

Protective clothing

(also called 'Anti-C protective Clothing') is used for work in areas presenting a significant contamination risk.
It mainly includes:
- fabric overalls;
- a filtering device;
- a hood;
- gloves;
- overboots;

Proven polluted site

Area polluted by a current or former industrial activity and on which is carried out an assessment of the ecological state of this medium or implemented an action plan.

R

Radioactive clean-up

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. Term equivalent to 'depollution' in the sector of contamination by radioactive substances.

Radioactive material

Radioactive substance for which subsequent use is planned or intended, after processing, if necessary.

Radioactive period (or 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 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. Final radioactive waste is radioactive 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.

Glossary

Radioactive waste conditioning	Operations intended to prepare radioactive waste for subsequent transport, disposal or disposal. *Note: These operations may include compaction, embedding, vitrification, cementation, bituminisation and containerisation.*
Radioactive waste disposal	Operation consisting in placing radioactive waste in a facility specially designed 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 potentially final disposal of radioactive waste. Disposal at surface, shallow depth or in deep geological formations may be considered, depending on the radiological risks associated with the waste.
Radioactive waste holders	Waste producer or any other person found in possession of waste (L. 541-1-1).
Radioactive waste packages	Conditioned and packaged radioactive waste packages.
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 alpha radioactivity, beta radioactivity (+, -, 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.
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/Radioisotope	Radioactive nuclide.

Rare earth element

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.

Rehabilitation, remediation

All the clean-up and redevelopment operations carried out to make a site suitable for a given use.

S

Scenario

Set of assumptions regarding events or types of behaviour, used to describe the possible evolutions of a system in time and space.

Secret basic nuclear installation (INBS)

This is a basic nuclear installation involving national defence.

Short-lived waste

Radioactive waste containing significant quantities of radionuclides with a radioactive half-life less than or equal to 31 years.

Source

Device, radioactive substance or installation able to emit ionising radiation or radioactive substances.

Source block package

These ILW-LL category packages contain spent sealed sources collected from 'small-scale nuclear activities' radioactive waste producers. The waste was conditioned in concrete packages between 1972 and 1985 with the aim of disposal.

The packages were then reconditioned in non-alloy steel containers and stored at Cadarache (Bouches-du-Rhône district) in 1994.

Spent fuel

Nuclear fuel discharged from a reactor after irradiation and stored in cooling pools.

Spent fuel processing

Operations performed on spent fuel from nuclear reactors in order to extract recoverable materials (e.g. uranium, plutonium) and condition the remaining waste.

Glossary

Storage **(of radioactive material or waste)** Operation consisting in temporarily storing radioactive substances at a specially designed surface or shallow facility until they can be recovered.

T

Toxic chemical Chemical substance or element liable to have harmful effects on human health in case of ingestion and/or inhalation. The health impact of a toxic chemical 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 toxic with threshold effect), or between a dose and a probability of effect (case of a toxic 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 geological radioactive waste disposal: arsenic, cadmium, cyanide, chromium, mercury, nickel, lead, antimony, selenium, boron, uranium, beryllium and asbestos.

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.

U

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.

V

Vinyl clothing (also called ‘Emmanuelle clothing’) is used when there is a risk of contamination by liquids.

In addition to the Anti-C protective clothing, it includes:

- an additional pair of gloves;
- a vinyl jacket with hood;
- vinyl trousers;
- overboots.

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.

VLLW

Very low level waste mostly coming from the operation, maintenance and dismantling of nuclear power plants, fuel cycle installations and research centres. The activity level of this waste is generally less than one hundred becquerels per gram.

W

Waste producer

Any person whose activity produces waste (initial waste producer) or any person performing waste treatment operations leading to a change in the nature or composition of this waste (secondary waste producer) (L. 541-1-1).

Waste treatment

Mechanical, physical or chemical operations intended to modify the characteristics of waste materials.

Processing may also be used to separate other elements.

Waste with technically-enhanced natural radioactivity (TENORM)

Waste generated by the transformation of raw materials naturally containing radionuclides which are not used for their radioactive properties; these radionuclides may be found concentrated, after transformation processes, in materials or waste requiring special management.

Z

Zircon

Zircon is a natural silicate ore ($ZrSiO_4$).

Glossary

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NATIONAL INVENTORY of Radioactive Materials and Waste

- Synthesis report
- Geographical inventory
- Catalogue of families
- Edition summary

Both the synthesis report and summary versions are available in multimedia format on a USB key and all the documents related to the *National Inventory* can be found on Andra's website **(www.andra.fr)**. Suggestions can also be registered by users directly on the site.

ANDRA
Mastering radioactive waste

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