National Inventory of Radioactive Materials and Waste

SYNTHESIS REPORT 2015









EDITORIAL



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or several decades, France has implemented a policy of responsible management of waste produced by activities using radioactive materials. At the beginning of the 1990s, the French Parliament approved the creation of Andra, the

French National Radioactive Waste Management Agency, a public undertaking independent of radioactive waste producers that is tasked with identifying and designing safe management solutions for all radioactive waste in France.

As part of its mission performed in the general interest, Andra is also responsible for making a periodic inventory of all radioactive materials and waste found in France and their future production. It strives to provide a picture of the nature, quantity and location of these materials that is as complete and exhaustive as possible. The law of 28 June 2006, which is now codified in the Environmental Code, provides that Andra will update annually and publish this information in the form of the present *National Inventory of Radioactive Materials and Waste* every three years.

For the sake of transparency, Andra created an interdisciplinary steering committee to monitor preparation of the National Inventory. Headed by Andra's chief executive officer, the steering committee includes representatives of key institutions (ministers, French Nuclear Safety Authority (ASN), High Committee for Transparency and Information on Nuclear Safety (HCTISN), etc.), waste producers, civil society and environmental protection organisations. It is a setting where all points of view on radioactive waste management issues can be expressed so that the National Inventory can fulfill a maximum number of expectations.

A vector for information and transparency on a subject that is a concern for our fellow citizens, the National Inventory also constitutes a valuable tool for guiding radioactive materials and waste management policy in France, formalised in the National Radioactive Materials and Waste Management Plan. The inventory ensures proper management of current and future waste. It also corresponds perfectly with the objective set by European Union Member States in the European directive on radioactive waste adopted on 19 July 2011, which recommends that each member state use inventories to draw up a national programme for the management of spent fuel and waste. On the basis of the declarations by each waste holder, the 2015 edition of the National Inventory presents waste produced as of 31 December 2013, as well as forecasts for the quantities of waste expected from now until 2020, 2030 and the end of life of the nuclear power plants and facilities. A longer-term forecast has also been produced for two alternative scenarios regarding the long-term future of France's nuclear power plants and energy policy. The National Inventory also presents radioactive materials kept in storage pending recovery.

THE NATIONAL INVENTORY CONSTITUTES A VALUABLE TOOL FOR GUIDING THE POLICY CONCERNING RADIOACTIVE MATERIALS AND WASTE MANAGEMENT IN FRANCE.

The 2015 edition of the National Inventory consists of five volumes:

• **Essentials** includes the overall figures for the National Inventory at the start of the year that are used in the National Radioactive Materials and Waste Management Plan, which is updated every three years;

 Synthesis Report, which offers a detailed description of all current and future radioactive materials and waste found in France;

• **Catalogue of Families**, which offers a detailed description of each family of radioactive waste, with a family defined as a type of waste having similar characteristics;

• Geographical Inventory, which presents each radioactive waste site in France;

Focus-on 2015, the version of the National Inventory prepared for the general public.

Andra has created a website dedicated to the 2015 edition of the National Inventory, www.inventaire.andra.fr. The new website will be updated annually and anticipates implementation of an open data policy for the National Inventory.

Since the 2012 edition, the synthesis report has been expanded to cover waste treatment and conditioning as well as dismantling and remediation of nuclear facilities. Worksite dismantling constitutes a significant source of waste; optimising management and particularly reducing the volume of waste produced represents a major challenge in the years ahead.

Andra is committed to improving both the form and content of the inventory in future editions. Since feedback from readers enables us to enrich the Inventory and make it more useful for as many people as possible, we welcome your comments. Yours sincerely,

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Pierre-Marie Abadie

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CHAPTER 1 RADIOACTIVE MATERIALS AND WASTE AND THEIR MANAGEMENT

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1.1 **SOURCES OF** RADIOACTIVE MATERIALS AND WASTE

The National Inventory sets out the sources of radioactive materials and waste, divided into **five economic sectors**, as a result of which radioactive waste is produced, held or managed:

 nuclear power sector, which includes mainly nuclear power plants, as well as facilities to manufacture and process nuclear fuel (mining and processing of uranium ore, chemical conversion and enrichment of uranium concentrates, fuel fabrication, spent fuel reprocessing, and recycling of part of the materials removed from spent fuel);

 research sector, comprising research for civil nuclear applications (mainly the research activities of CEA, the French Alternative Energies and Atomic Energy Commission), as well as research laboratories in various fields such as medicine, nuclear and particle physics, agronomy, chemistry and biology;;

 defence sector: this covers mainly French military and nuclear deterrence activities, including nuclear-powered ships and submarines, as well as the associated research activities; industries other than nuclear power, including rare earth mining, manufacture of sealed sources, and various other applications such as weld inspection, medical equipment sterilisation, food sterilisation and preservation, etc.;

medical sector, which includes diagnostic and therapeutic activities.

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

In accordance with Book V, Title IV, Chapter II, Article L. 542-1 of the French Environmental Code, **the producers of radioactive waste are responsible for proper management of their waste until it has a final disposal solution**.

Most radioactive materials and waste produced by the nuclear power industry come from facilities that manufacture, use, and then recycle or store nuclear reactor fuel.

NATURAL AND ARTIFICIAL RADIOACTIVITY

Radioactive substances may be of natural origin or the result of human activities.

There are many sources of naturally occurring radioactivity: ores and materials containing radionuclides naturally present in the environment (uranium and thorium isotopes, tritium, potassium-40, carbon-14, or daughter elements such as radium and radon), cosmic radiation, and so on. These natural radionuclides are dispersed throughout all biosphere compartments. The concentration of radionuclides varies widely depending on the material and its origin: exposure to radionuclides of natural origin can vary by more than one order of magnitude in the various regions of the world (from an average of 2.4 mSv/year in France to more than 250 mSv/year in some parts of India or Brazil).

Since the beginning of the 20th century, many uses of the properties of radioactivity have generated radioactive materials and waste. Most of the waste comes from nuclear power plants, spent fuel reprocessing plants and other civil and military nuclear facilities that have developed over the past decades.

Research laboratories and nuclear medicine centres also contribute to the production of radioactive waste, albeit to a lesser degree, as do certain other industries that use radioactive substances.

ARTICLE L.542-1-1 OF THE FRENCH ENVIRONMENTAL CODE

Book V, Title IV, Chapter II, Article L. 542-1-1 of the French Environmental Code, stipulated by the Act of 28 June 2006 [1], 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, the activity or concentration of which justifies radiological protection monitoring."

This refers mainly to nuclear fuel, plutonium and natural, enriched, depleted or recycled uranium. Other radioactive substances are waste.

"A radioactive material is a radioactive substance for which subsequent use is planned or intended (after processing, if necessary)."

In the process of producing electricity, for example, spent fuel still contains materials that can be used. These are processed in France to extract plutonium and uranium.

In some cases, processing such materials for recycling purposes can generate waste.

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

In France, there is no single activity or concentration threshold per radionuclide to determine whether radiological protection monitoring is justified.

Pursuant to Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom, most countries adopt an approach based on clearance, which corresponds to the release of a material from regulatory control. Some countries implement clearance levels expressed as specific activity (Bq/g), which are either universal (regardless of the material, its origin and destination) or dependent on the material, its origin and destination.

In France, for nuclear activities conducted at basic nuclear installations and secret basic nuclear installations and for nuclear activities authorised or declared under Article L. 1333-4 of the

Public Health Code, and referred to in Article R. 1333-12 of the same Code, as a precaution, any contaminated or activated waste, or waste that is liable to be so, must undergo specific, rigorous management, including disposal of final waste in a dedicated radioactive waste facility. French regulations do not provide for clearance of very low-level waste.

For other nuclear activities, whether or not radiological monitoring is justified is determined in accordance with the provisions of the Public Health Code, taking account of the three basic principles of radiation protection, i.e. justification, optimisation and dose limitation, and of the fact that the total effective dose due to nuclear activities received by any member of the public must not exceed 1 mSv per year. Consequently, if an acceptability study on the radiological impact of waste management shows that radiological protection monitoring is not justified, this waste may, under certain conditions, be accepted in conventional disposal facilities. This is particularly the case for waste containing technologically enhanced, naturally occurring radioactive material (TENORM).

TENORM waste is waste generated by the processing of raw materials that contain naturally occurring radionuclides but are not used for their radioactive properties. In fact, all substances, and especially minerals, contain trace amounts of naturally occurring radioactive elements, including uranium, thorium or potassium. Some non-nuclear industries related to chemicals, metallurgy or energy production can be a source of TENORM waste due to production or extraction processes that lead to concentration of the levels of natural radionuclides.

"A nuclear fuel is regarded as spent fuel when it has been irradiated in the core of a reactor and withdrawn definitively."

As France has opted for reprocessing of spent fuel to recover the reusable materials it contains whenever possible, such fuel is not considered to be radioactive waste.

Activities involving the use of 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 are described and quantified in the public reports that their operators are required to issue each year under the Act of 13 June 2006 relative to Transparency and Security in the Nuclear Field. The data concerning discharges from installations classified on environmental protection grounds is gathered each year by the ministry responsible for ecology and made available online to the general public.

[] Planning Act 2006-739 of 28 June 2006 on the sustainable management of radioactive materials and waste, codified in the Environmental Code.

NOTE

Waste producer

"Any person whose activities generate waste (initial waste producer) or anyone who carries out waste-processing operations that result in a change in the nature or composition of this waste (secondary waste producer)." (L. 541-1-1)

Waste holder

"Producer of waste or any other person who is in possession of 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 disposal (successively the holder-producer, then the transport entity, the operator of the storage site and the operator of the disposal site).

Waste management

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

Responsibilities

"Any producer or holder of waste is required to manage it, or

have it managed, in compliance with the provisions set out in this chapter.

"Any producer or holder of waste 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.

"Any producer or holder of waste must ensure that the person to whom it passes the waste is licensed to handle it." (L. 541-2)

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

These provisions mean that producers are responsible for their waste and the obligations placed on them until its final disposal pursuant to 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).

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

MANDATORY 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 paragraph 1 of Article L. 542-12, any operator of a site hosting one or more basic nuclear installations, or one or more defence-related nuclear facilities, defined in Article R. 1333-37 of the French Defence Code, or one or more facilities classified for environmental protection in the case of the nuclear activities referred to in the appendix(1) to Article R. 511-9 of the French Environmental Code, or several of these categories of facilities, is required to submit annually to Andra an inventory of the radioactive materials and waste on that site, as at 31 December of the previous year.

"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 reprocessing 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 the 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. 1333-10 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 submit annually to Andra an inventory of the radioactive waste stored, as at 31 December of the previous year, and showing the management solution used".

• "Art. R. 542-69. Any operator of a site mentioned in Article R. 542-67 is required to submit to Andra, once every three years, a report providing information for that site concerning the projected quantities of radioactive materials by family. If no permanent management solution suitable for such waste has been adopted, the report shall give details of the types of storage facilities envisaged, their available capacities and their anticipated operating lifetime.

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

[] Decree 2008-875 of 29 August 2008 implementing Section 22 of Planning Act 2006-739 of 28 June 2006 on the sustainable management of radioactive materials and waste.

1.2 **CLASSIFICATION OF** RADIOACTIVE WASTE AND MANAGEMENT SOLUTIONS

There are many characteristics that distinguish one type of waste from another, such as its physical and chemical nature and the level and type of radioactivity. Radioactive waste usually contains a mixture of radionuclides: uranium, caesium, iodine, cobalt, radium, tritium, etc. Radioactive waste usually contains a mixture of radionuclides: uranium, caesium, iodine, cobalt, radium, tritium, etc.

Radioactive waste classification in France is primarily based on two parameters, which are important when determining the appropriate management method [III]: the activity level and the radioactive half-life of the radionuclides contained in the waste.

A distinction is made between the following waste activity levels:

- very low-level waste (VLLW);
- Iow-level waste (LLW);
- intermediate-level waste (ILW);
- high-level waste (HLW).

DEFINITION

The radioactive half-life expresses the time it takes for the initial activity of a radionuclide to be halved.

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

• very short-lived (VSL) waste, which contains radionuclides with a half-life of less than 100 days;

 short-lived (SL) waste, whose radioactivity comes mainly from radionuclides with a half-life of less than or equal to 31 years;

Iong-lived (LL) waste, which contains a significant quantity of radionuclides with a half-life of more than 31 years.

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

There are thus five categories of waste that require or will require special management. Managing very short-lived waste involves storing it until its radioactivity decays.

Depending on its composition, waste has higher or lower levels of radioactivity lasting for varying periods of time.



HIGH-LEVEL WASTE (HLW)

Although this waste represents only a small volume, it accounts for most waste-related radioactivity. The activity level of HLW is several billion becquerels (Bq) per gram. This type of waste comes for the most part from the nuclear power industry and related research, and, to a lesser extent, from the defence industry. It mainly arises from reprocessing spent fuel. Most of this waste is vitrified in stainless steel containers. Because of its high radioactivity, this type of waste gives off heat.

It contains:

- short-lived fission products such as caesium-134 and caesium-137;
- long-lived fission products such as technetium-99;

 activation products and minor actinides, some of which have halflives of several thousand years, such as neptunium-237.



Metal waste package for vitrified HLW

[III] Decree 2013-1304 of 27 December 2013 implementing Article L. 542-1-2 of the Environmental Code and setting out the provisions concerning the National Radioactive Materials and Waste Management Plan.

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

This waste mainly comes from spent fuel reprocessing and activities involved in the maintenance and operation of processing plants. It comprises structural waste from fuel assemblies (end caps and cladding hulls), technological waste (used tools, equipment, etc.) and waste resulting from the treatment of effluents, such as certain types of sludge. It is characterised by the presence of significant amounts of long-lived radionuclides such as nickel-63 (half-life: 100 years).

Other types of ILW-LL originate from components that have been activated while exposed to neutron flux in a reactor.

The activity of this waste ranges between one million and one billion becquerels per gram, i.e. lower than that of HLW by a factor of 10 to 100.



Waste metal from the structures surrounding spent fuel (hulls).

6

HLW and ILW-LL are currently stored pending a long-term management solution. Article L. 542-12 of the Environmental Code adopts deep geological disposal as the reference solution for this waste and tasks Andra with conducting studies and research to select a site and design a deep reversible disposal facility (at a depth of 500 metres) to accommodate this waste. In accordance with the schedule laid down by law, the Cigeo geological disposal facility is due to be commissioned in 2025, subject to licensing.



ILW-

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

This consists mainly of two types of waste:

• Radium-bearing waste mostly arises from non-nuclear industrial activities such as some types of research and rare earth minerals processing. Other radium-bearing waste comes from the cleanup of legacy sites contaminated with radium, which Andra is making safe as part of the activities it performs in the general interest. The level of radioactivity of this waste is usually between a few tens and a few thousands of becquerels per gram. The radionuclides that it contains are mainly long-lived alpha emitters such as radium, uranium or thorium;

• graphite waste comes from operation and dismantling of the first nuclear power plants (gas-cooled graphite-moderated reactors, GCRs) and certain experimental reactors that have been decommissioned. This type of waste has a level of radioactivity between 10,000 and 100,000 becquerels per gram and contains mainly long-lived beta-emitting radionuclides. In the short term, the activity of graphite waste is primarily 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 comprises other types of waste, such as **spent sealed sources**, certain **legacy bitumen packages and uranium conversion treatment residues**.

Near-surface disposal of this waste is currently being studied within the framework of Article L. 542-1-2 of the Environmental Code.



Fuel rod used at Chinon



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

This mainly comprises waste related to maintenance (clothing, tools, filters, etc.) and operation (liquid effluent treatment or gaseous effluent filtering) of nuclear power plants, fuel cycle facilities and research centres. It can also come from dismantling operations on these facilities.

LILW-SL contains short-lived radionuclides with a maximum half-life of 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 and one million becquerels per gram.

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 dedicated sites in France for the disposal of LILW-SL: the CSM and CSA waste disposal facilities.

No waste has been taken to the CSM disposal facility since 1994; it is currently in the monitoring phase. The CSA facility has been in operation since 1992, in the municipalities of Soulaines-Dhuys, Épothémont and Ville-aux-Bois.

The category of LILW-SL includes low- and intermediate-level shortlived waste containing a significant quantity of tritium (T-LILW-SL). Although tritium is a short-lived radionuclide, it is difficult to confine and can easily migrate into the environment where it may leave detectable traces.

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 in 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.



VERY LOW-LEVEL WASTE (VLLW)

VLLW mainly comes from the operation, maintenance and dismantling of nuclear power plants, fuel cycle facilities and research centres. It also originates from conventional industries using naturally occurring radioactive materials. It usually takes the form of inert waste (concrete, rubble and earth) or metal waste.

VLLW production will increase considerably as large-scale dismantling begins on the nuclear power plants currently in operation, or on fuel cycle facilities and research centres.

The level of radioactivity of this waste is generally less than 100 becquerels per gram.

This waste is disposed of at the Cires waste collection, storage and disposal facility, which was commissioned in August 2003 and is located in the municipalities of Morvilliers and La Chaise in northeastern France.



Metal VLLW disposed of at Cires



Some waste, mainly hospital waste, contains very-short-lived radionuclides (with a half-life of less than 100 days), which are used for diagnostic or therapeutic purposes. This waste is stored on-site until its radioactivity has decayed, which takes from a few days to a few months. It is then disposed of using conventional methods.

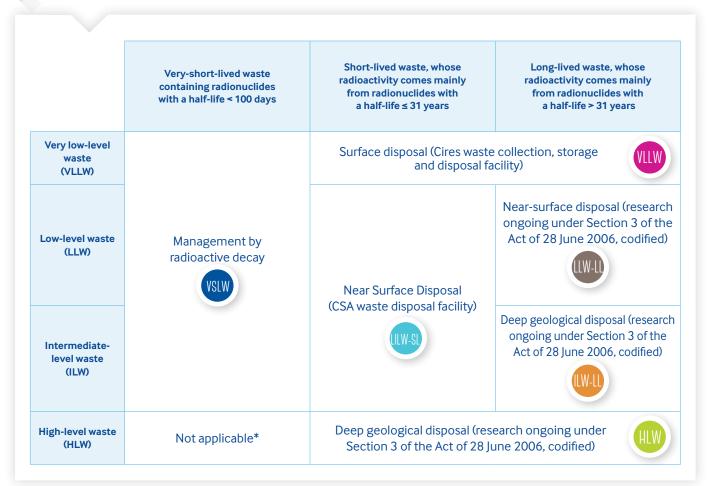


Decay containers

Broadly speaking, with this classification, one or more management solutions can be assigned to each waste category (see Report 1).

The table below summarises the radioactive waste classification principles and the associated management solutions.

CLASSIFICATION OF RADIOACTIVE WASTE AND ASSOCIATED MANAGEMENT SOLUTIONS



^{*}The category of very-short-lived high-level waste does not exist.

The usual classification of waste, taking account of the activity level of the radionuclides and their half-lives, means that radioactive waste can be routed towards the management solution best suited to its characteristics.

It does not, however, take into consideration certain complex factors that lead to a management solution being adopted that differs from the one normally corresponding to the category to which the waste belongs.

Other criteria, such as stability or the presence of toxic chemicals, must also be borne in mind.

Furthermore, the definition of a management method must also take into account the general principles set down in Book V, Title IV, Chapter I of the Environmental Code, particularly the need to reduce the volume and harmfulness of final radioactive waste.

Two important points regarding the classification of radioactive waste should therefore be noted:

• there is no single classification criterion that determines the class of a waste item. The radioactivity of the various radionuclides in the waste must be examined to assign it a position in the classification. However, for want of a single criterion, the waste assigned to each category generally falls into a specific radioactivity range, as indicated in the previous table;

• waste may appear to fit into a defined category yet, because of other characteristics (such as its chemical composition), may not be accepted in the corresponding management solution.

Moreover, waste management options can evolve in the light of advances made in knowledge about waste when it is recovered or when facilities are dismantled, and as a result of progress made in studies concerning optimisation of treatment and conditioning methods.

1.3 SPECIAL CASES

WASTE CONTAINING TECHNOLOGICALLY ENHANCED, NATURALLY OCCURRING RADIOACTIVE MATERIAL

Technologically enhanced, naturally occurring radioactive material (TENORM) waste **is generated by the processing of raw materials that contain naturally occurring radioactive material (NORM)**, but which are not used for their radioactive properties.

These radionuclides may be found in materials or waste and require special management.

The naturally occurring radionuclides taken into account for TENORM waste are potassium-40 and those in the uranium-238 and thorium-232 decay series; all of these are found in materials used in industrial processes. These processes can concentrate or enhance the natural radioactivity present in some products used, particularly in the residues they generate.

This type of waste is not derived from nuclear activities. It consists mainly of waste from the chemical or metallurgy industries (phosphate fertilisers, rare earth elements, zircon sand, etc.).

The Circular of 25 July 2006[IV] provides the possibility for specific management of this particular waste in a strict framework with acceptance in a conventional waste disposal facility.

Examples of this might be the disposal of waste from the demolition of old factories, equipment or process residues.

Management solutions and an inventory are set out in Report 5.



Residues from the production of rare earth elements

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 handled using existing management solutions in view of some of their characteristics, and especially their chemical characteristics, or because treatment or conditioning processes are not available or particularly complex to develop, given the sometimes small quantities involved.

Examples include some oils and organic liquids that cannot be incinerated, or waste containing mercury.

The development and implementation of treatment processes for this kind of waste is monitored under the National Radioactive Materials and Waste Management Plan.



WASTE CONCERNED BY A LEGACY MANAGEMENT METHOD

The management methods for radioactive waste have changed over time.

In most cases, the mining waste listed in the *National Inventory* has been **disposed of permanently on or near former mining sites**.

Other types of waste have been managed close to the production sites or used as backfill.

Lastly, waste has been dumped at sea by various European countries.



For more information, see Chapter 4.



Sea dumping of radioactive waste

1.4 GENERAL PRINCIPLES OF RADIOACTIVE WASTE MANAGEMENT

MANAGEMENT POLICY

The principles governing management of radioactive waste are strictly regulated at both national and international levels. Moreover, France has signed 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.

1 At European level

On 19 July 2011, the European Council adopted a Directive [VI] establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste, from generation to disposal.

This Directive covers all stages of the management of spent fuel and radioactive waste resulting from civilian activities. Each Member State has ultimate responsibility for managing the spent fuel and radioactive waste generated on its territory.

The Directive requires each Member State to establish and maintain a national framework that provides for the following: a national programme for the management of spent fuel and radioactive waste, licensing, the creation of inventories, a control system and inspections, enforcement actions such as the suspension of activities, the allocation of responsibility, public information and participation, and funding schemes for waste management. Furthermore, the Directive stipulates that each Member State shall establish and maintain a competent regulatory authority in the field of spent fuel and radioactive waste management, and lays down certain conditions to ensure the authority's independence.

2 At national level

France has defined and implemented a rigorous public policy on radioactive waste. This was defined in a legislative framework in 1991 (in the Act of 30 December 1991 [VII]) then consolidated in 2006 (with the Act of 28 June 2006, codified in the Environmental Code).

This policy is managed by the Directorate-General for Energy and Climate (DGEC) at the ministry responsible for energy, and is based on three main elements: • a National Radioactive Materials and Waste Management Plan [VIII]. The plan is updated by the Government every three years and defines a scheduled programme of research and other activities;

 provisions for independent evaluation of research, public information and dialogue with all stakeholders;

guaranteed funding: in accordance with Article L. 110-1 of the French Environmental Code, which stipulates that "the costs arising from measures to prevent, reduce or combat pollution must be borne by the polluter", it is for the producer of the waste to finance its management, including long-term.

3 French law

Article L 541-1 of the Environmental Code lays down the following principles: prevention or reduction of waste production, producers' responsibility until disposal of their waste, traceability and the need to inform the public.

Regarding radioactive waste, the Environmental Code, as amended by the Act of 28 June 2006, states that "the sustainable management of any radioactive materials and waste, resulting in particular from the operation or dismantling of facilities using radioactive sources or materials, shall be carried out in compliance with the requirements relating to the protection of human health, safety and the environment" (Article L. 542-1).

Numerous provisions are implemented to comply with this legislative framework:

 requirements concerning treatment and conditioning, transport and facilities: these are defined by the competent authorities, which subsequently monitor their application;

procedures to reduce the volume and harmfulness of such waste; then, for the waste generated, operations concerning sorting, treatment, conditioning and characterisation of its radiological content: these are defined and implemented by the producers of the waste. The research and development work that is often required is carried out by various organisations, and especially by the CEA;

[V] Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, available at: www-ns.iaea.org/conventions/waste-jointconvention.asp

[VI] Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste.
 [VII] Act 91-1381 of 30 December 1991 on research into radioactive waste management.

[[]VIII] French National Radioactive Materials and Waste Management Plan, available at http://www.developpement-durable.gouv.fr

• the design and construction of waste facilities with the required safety level. These may be storage facilities (temporary solution), which are generally the responsibility of waste producers, or disposal facilities (permanent solution), for which Andra is responsible (see Report 1);

 transport, storage and disposal operations, along with traceability and monitoring, including over the long term in the case of disposal facilities;

provisions relating to public information.

ENTITIES INVOLVED IN RADIOACTIVE WASTE MANAGEMENT

1 Institutional framework

The French National Radioactive Materials and Waste Management Plan uses the data from the National Inventory as a basis for reviewing existing management strategies, estimating foreseeable demand for storage and disposal facilities and determining the objectives regarding radioactive waste for which no definitive management solution has yet been found.

• The Directorate-General for Risk Prevention (DGPR) at the ministry responsible for the environment deals with matters relating to sites contaminated by radioactivity (see Chapter 4) and waste with high natural radioactivity (see Chapter 3), and defines regulations applicable to installations classified on environmental protection grounds, including conventional waste disposal facilities.

Concerning scientific issues in general, and those relating to nuclear programmes in particular, the French Parliament has set up its own evaluation body: the Parliamentary Office for the 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 Board (CNE), which is tasked with annually evaluating the progress and quality of research on the management of radioactive materials and waste. This Board was set up under the Act of 30 December 1991, and confirmed by Article L.542-3 of the Environmental Code. The Board publishes an annual report that is submitted to Parliament [IX] and made public.

• The National Committee for the Evaluation of Funding (CNEF) for the costs of dismantling basic nuclear installations and managing spent fuel and radioactive waste is a committee created by the Act of 28 June 2006 in order to monitor the funding of long-term nuclear costs.

• The High Committee for Transparency and Information on Nuclear Safety (HCTISN) is a forum for information, consulting and debate concerning risks involved in nuclear activities and their impact on human health, the environment and nuclear safety. It was created by the Act of 13 June 2006 relative to transparency and security in the nuclear field [X]. The Committee's reports and recommendations can be consulted at www.hctisn.fr.

• The French Nuclear Safety Authority (ASN) is an independent administrative authority set up under the Nuclear Security and Transparency Act of 13 June 2006:

- it is tasked, on behalf of the French Government, with regulating nuclear safety and radiation protection. It monitors 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;
- it grants individual licences for the possession of certain radioactive sources or equipment using ionising radiation.

2 Producers of radioactive waste

In accordance with Book V, Title IV, Chapter II, Article L. 542-1 of the French Environmental Code, the producers of radioactive waste are responsible for proper management of their waste until it has a final disposal solution. In particular, they have to sort the waste and define the methods for its treatment and conditioning, depending on the technologies available, with a view to reducing the quantity and harmfulness of radioactive waste.



Storage area in AREVA's R7 vitrification facility at La Hague in Normandy

[IX] The National Assessment Board's reports are available at www.cne2.fr

[XI] Order of 7 February 2012 laying down the general rules on basic nuclear installations.

X] Act 2006-686 of 13 June 2006 relative to Transparency and Security in the Nuclear Field.

They carry out waste conditioning in accordance with the strict quality assurance procedures required by regulations [XI]. They must also store waste for which no final disposal solution is currently available.

In addition, they are responsible for transporting conditioned waste to Andra's disposal facilities.

For some producers that do not have suitable resources, due to the small quantities of radioactive waste they generate, such as non-CEA research laboratories or hospitals, Andra is usually responsible for waste collection, treatment, conditioning and storage.

3 The role of Andra

Andra, the French National Radioactive Waste Management Agency, is responsible for the long-term management of radioactive waste produced in France.

It is an industrial and commercial public undertaking whose role was defined by two successive acts of French legislation:

• Act of 30 December 1991 on research into the management of high-level long-lived radioactive waste. This act created Andra as a public body and entrusted it with the task of conducting research on the deep geological disposal of high- and intermediate-level long-lived radioactive waste.

 Planning Act of 28 June 2006, codified in the Environmental Code, on the sustainable management of radioactive materials and waste. This act extended and strengthened Andra's role and the scope of its activities.

Placed under the supervision of the French ministries for energy, ecology and research, Andra implements the French Government's radioactive waste management policy. It is independent of radioactive waste producers.

The Government sets out Andra's objectives in a performance target agreement. The latest version covers the period from 2013 to 2016 and can be consulted on Andra's website (www.andra.fr).

Andra places its expertise and know-how at the service of the Government to design management solutions and operate disposal facilities for all radioactive waste produced in France, ensuring longterm protection for human health and the environment against the impact of this waste.

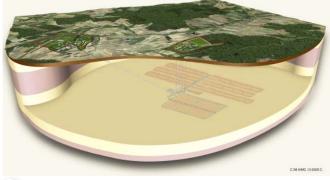
The French Environmental Code specifies Andra's activities:

- Design, scientific research and technological development:
 - designing and implementing sustainable solutions for the management of high-level waste (HLW), intermediate-level long-lived waste (ILW-LL) and low-level long-lived waste (LLW-LL) that is placed in storage.

- Industrial activities:
- managing radioactive waste produced by the nuclear power, research, defence, industrial and medical sectors;
- operating and monitoring radioactive waste disposal facilities so as to protect people and the environment.
- Public service and information:
 - retrieving radioactive objects from private individuals and local authorities;
 - cleaning up and remediating radioactively contaminated sites, where the owners have disappeared or failed to fulfil their obligations (see Chapter 4);
 - drawing up an annual national inventory of radioactive materials and waste in France and publishing it once every three years;
 - providing clear and verifiable information on the management of radioactive waste;
 - · promoting meetings and dialogue with all stakeholders.

Promotion of expertise in France and abroad:

- developing scientific collaboration throughout France and the world;
- promoting Andra's entire range of services throughout France and the world;
- disseminating scientific and technical culture as widely as possible.



Proposed Cigeo geological disposal facility for high-level and intermediate-level long-lived waste



A Lorry used to collect LILW-SL from private individuals

1.5 **GENERAL PRINCIPLES OF** RADIOACTIVE MATERIALS MANAGEMENT

MANAGEMENT POLICY

Radioactive materials mostly comprise fuel, uranium, plutonium and recoverable materials from industries other than the nuclear power industry (mainly materials containing thorium). Most of these materials are generated by the nuclear fuel cycle.

The various categories of radioactive materials presented in this report are as follows:

Natural uranium (mined, enriched, depleted);

Uranium from spent fuel reprocessing (after reprocessing, enriched);

• Uranium oxide fuel (UOX or ERU) from nuclear power reactors (scrap, new, in use or awaiting reprocessing);

 Uranium and plutonium mixed oxide fuel (MOX) from nuclear power reactors, fuel from the Superphénix and Phénix reactors (scrap, new, in use or awaiting reprocessing);

- Fuel from research reactors (new, in use or awaiting reprocessing);
- Spent fuel for defence purposes
- Plutonium;
- Thorium;
- Materials in suspension;
- Other materials.

ENTITIES INVOLVED IN RADIOACTIVE MATERIALS MANAGEMENT

The institutional framework for the management of nuclear materials

is virtually identical to that for radioactive waste management.

The following are the main owners of nuclear materials:

 AREVA is involved in all aspects of the fuel cycle, except the use of nuclear fuel. This cycle covers uranium mining, concentration, conversion and enrichment, fuel fabrication and reprocessing/ recycling of spent fuel;

- The CEA uses the fuel for research purposes;
- EDF uses the fuel to generate electricity;

 SOLVAY: extracts rare earth elements from ores that also contain thorium;

 National defence: activities associated with nuclear deterrence and nuclear propulsion of various ships and submarines, along with the associated research.

The medical sector uses nuclear materials (depleted uranium) as biological shielding, but only marginally.

Inspection of nuclear materials

Given the scale of its nuclear industry and aware of its responsibilities regarding non-proliferation, France has set up one of the most effective regulatory systems in the world, covering both civil nuclear materials and those relevant for national security.

At a national level, protection and inspection of nuclear materials is subject to specific regulations that come under the Defence Code and related regulatory documentation.

Six materials are covered by French legislation: **plutonium**, **uranium**, **thorium**, **tritium**, **deuterium** and **lithium-6** (deuterium and lithium-6 are not radioactive). Their definition is periodically reviewed to reflect changing knowledge and technology.

The regulations aim to prevent the loss, theft or diversion of nuclear materials and to protect these materials and related facilities or shipments against malicious acts.

In this context, the regulations require operators and industrial facilities holding these materials to comply with a number of provisions that complement each other, such as:

 physical protection measures to protect the materials against malicious acts or sabotage by placing barriers and other devices between publicly accessible areas and the premises holding the materials;

 monitoring of the materials so that their location and use is known at all times;

 accounting measures so that the exact quantity of the materials held is known at all times. Each operator must keep their own accounts, which are regularly compared with centralised accounts held by the French Institute for Radiological Protection and Nuclear Safety (IRSN). For plutonium, such accounts shall be kept to the nearest gram;

containment measures to prevent unauthorised movement of materials;

 surveillance measures with the aim of ensuring the integrity of containment and verifying that no material has been released illegally.

Possession of materials by an operator requires prior authorisation by the competent authority, which in France is the Senior Defence and Security Official of the ministry responsible for energy. This authorisation is issued only after examination of documentation provided by the operator, detailing physical protection, monitoring, accounting, etc. The examination is carried out by IRSN, which is authorised to act on behalf of the ministry.

The granting of authorisation requires the operator to undertake a safety study in order to assess the effectiveness and relevance of the protection against key threats defined by the government. The threats are reviewed periodically by specialised government agencies to reflect the changing national and international situation.

At international level, inspections to ensure compliance with the Non-Proliferation Treaty and the Euratom Treaty are carried out by the IAEA and the European Commission, respectively. These inspections cover both the declaration and monitoring of the movement of nuclear materials (plutonium, uranium and thorium) between countries and declarations concerning flows and stocks of materials held at national level in the case of nuclear materials that are not concerned with national security. These international inspections involve inspections of French facilities by Euratom inspectors and, to a lesser extent, by the IAEA (trilateral agreement between the IAEA, Euratom and France).



Fuel in the spent fuel pool



Fuel rods

UN 3321 - Matieres radioactives de faible activité specifique (LSA-II)

24000 Kg type IP - 2

Epedieur

AREVA NC Employment de Remolate - BF /6 36/01 Fierzolate Ceder - France



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This chapter sets out overall statements of the declarations made by the producers or holders of radioactive materials and waste during 2014. In conformity with Decree 2008-875 of 29 August 2008 and with the Order of 9 October 2008 amended by the Order of 4 April 2014, these declarations concern:

- the stocks of radioactive materials and waste as at 31 December 2013;
- the forecasts concerning radioactive materials and waste for the reference dates and at end of facility life according to the industrial scenarios;
- the forecasts concerning radioactive waste at end of facility life according to the planning scenarios.

In contrast to the stocks that have to be declared by all producers or holders of waste or materials, forecasts are required only for operators of basic nuclear installations, defence-related facilities (secret basic nuclear installations and experimental facilities and sites), or nuclear installations classified on environmental protection grounds (terms in the nomenclature for radioactive substances).

In all, nearly 1,200 geographical sites within the meaning of the National Inventory (see appendix 1) on which radioactive waste was located at the end of 2013 are listed in the 2015 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 waste producers only account for a small proportion of the volume of radioactive waste present in France.

Details of the sites listed are to be found in the Geographical Inventory, this edition of the National Inventory and at www.inventaire.andra.fr.

In its first part, this chapter provides a quantitative overview of the radioactive waste present at the end of 2013 and the waste that will be generated by 2020, 2030 and at end of facility life. The forecasts are based on industrial scenarios. The only waste evaluated are those generated by facilities (due to their operation and dismantling) for which the construction licence is dated on or before 31 December 2013.

In the second part of this chapter, a list of the radioactive materials present at the end of 2013 and expected by the end of 2020 and the end of 2030 is also set out.

Lastly, a forward-looking view of the radioactive waste likely to be generated by all the facilities licensed as at the end of 2013 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 specific energy scenarios: ongoing production of nuclear power,

non-renewal of nuclear power production facilities.

THE SCOPE OF THE WASTE TAKEN INTO ACCOUNT IN THE STATEMENTS PRESENTED

The waste taken into account for the statements set out in this chapter do not include waste dealt with using "legacy" management methods. These waste include:

residues from treatment of uranium ores that are disposed of on certain former mining sites. The National Inventory lists 20 sites on which these residues are disposed of;

legacy waste disposed of in the past close to nuclear facilities or plants. It usually takes the form of mounds or backfills;

waste dumped at sea.

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 waste (VSLW) 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, uranium conversion treatment residues from the AREVA plant in Malvési are shown separately: in 2014 and 2015, under the National Radioactive Materials and Waste Management Plan, AREVA submitted studies concerning long-term management of this waste. Pending a decision, the family is shown separately in the statements setting out figures for the stocks of waste existing at 31 December 2013, and in the forecasts. Most of this waste is stored in settling and evaporation ponds, and is not conditioned.

These exclusions concern all the statements included in Chapters 2 and 3. They are not mentioned again below.



2.1 RADIOACTIVE WASTE

Radioactive waste is defined in Article L. 542-1-1 of the Environment Code as "radioactive substances for which no subsequent use is planned or intended.

Final 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."

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

Five economic sectors are defined as follows:

1 NUCLEAR POWER

which is mainly made up of nuclear power plants, together with the plants dedicated to production and treatment of nuclear fuel (extraction and treatment of uranium ore, chemical conversion and enrichment of uranium concentrates, fuel manufacture, spent fuel reprocessing and recycling of some of the material extracted from the spent fuel).

2 RESEARCH ···········

which includes research in the civil nuclear field, research laboratories in the medical, nuclear and particle physics, agronomy, chemistry, biology sectors, etc.

3 DEFENCE ······

which mainly covers activities linked with the armed forces and nuclear deterrent weapons, including the nuclear propulsion systems of certain ships and submarines, together with the corresponding research activities.

(OTHER THAN 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.

MEDICINE

which includes diagnostic and therapeutic activities (scintigraphy, radiotherapy, etc.).

The volume of radioactive waste identified since the beginning of its production up to 31 December 2013 is about **1,460,000 m³** (as disposed volume), i.e. about 140,000 m³ more than at the end of 2010.

Some **73% of this waste is already definitively disposed** of in Andra's facilities: VLLW at Cires and LILW-SL at the CSM and CSA waste disposal facilities. The remaining waste 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:
 buffer storage of conditioned waste in the form of packages, of a logistical nature, enabling management of the flows to Andra's 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,
 storage of high-level waste, which has to be stored for several
 - decades to decay and cool down, before it can be placed in deep underground disposal facilities.

UNITS OF VOLUME

The unit adopted to draw up the statements is the **"as disposed"**. It allows the waste to be accounted for using a single, common unit. The forecasts also use this unit.

For waste for which the conditioning is not yet known, assumptions are performed to assess the as disposed.

For deep underground disposal, further conditioning in a primary package known as a disposal package may be necessary for handling, safety or reversibility. At this stage of the design studies for the Cigeo project, the volume of the HLW disposal packages could be two or three times greater than the volume of the primary packages, while the volume of the ILW-LL packages could be five or six times greater.



O

The volumes of waste listed correspond to the volumes of conditioned waste, i.e. for which no further processing is envisaged by its producers before disposal. This conditioned waste constitutes primary packages.



BREAKDOWN OF RADIOACTIVE WASTE BY CATEGORY AT THE END OF 2013

Stocks at the end of 2013

The volumes of radioactive waste in France as at 31 December 2013, including waste from other countries to be returned to those countries (see "Waste from outside France" box on page 29), are shown in the table and chart below.

IN THE TABLE, THE VOLUMES ARE COMPARED WITH THOSE AT THE END OF 2010 (2012 EDITION OF THE NATIONAL INVENTORY).

Category	Volume at the end of 2013*	Difference for 2013 - 2010**
HLW	3,200	500
ILW-LL	44,000	4,000
LLW-LL	91,000	4,500
LILW-SL	880,000	52,000
VLLW	440,000	77,000
DSF***	3,800	200
Grand total	~1,460,000	~140,000

* The volumes are rounded.

**The differences were calculated on the basis of the exact figures and then rounded.

*** Waste without a specific disposal solution 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 AREVA plant in Malvési, whose longterm management method is currently being defined, the results are:

Category	Volume (m ³) at the end of 2013	Difference for 2013 - 2010 (m ³)
uranium conversion treatment residues	690,000	90,000

 for non-conditioned waste, the conditioning assumptions adopted for the statements are those made by the producers, even though some of the assumptions are still being studied or have not yet been validated by the French Nuclear Safety Authority (ASN) or accepted by Andra with a view to disposal;

 the waste from dismantling operations is included if the dismantling operation has actually been completed as at 31 December 2013;

• thus the graphite LLW-LL still in the GCR reactors (reactor stacks, reflectors in place, support areas) is not included in the stocks at the end of 2013 but it is taken into account in the forecasts concerning volumes of waste, depending on the actual dismantling date;

• 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 predetermine acceptance of the waste at a disposal facility;

• the waste from outside France referred to in Article L. 542-2-1 of the Environment Code, which is to be returned to the customer in its country of origin, is included in the waste on the site of the AREVA NC plant at La Hague and the CEA site at Marcoule;

spent sources other than lightning rods (sealed sources, smoke detectors, source rods, source clusters, etc.) are included in a special family not linked to the waste classification management solutions, except for the legacy packages stored at Cadarache ("source block" ILW-LL packages). In this National Inventory, no as disposed volume is allocated to these sources, due to the variability of the possible management and conditioning assumptions at this stage. Lightning rods are assigned to two families of LLW-LL. Report 4 contains a list of these sources and lightning rods.

WASTE FROM OTHER COUNTRIES

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 involved in treating spent nuclear fuel or radioactive waste, and it was reaffirmed and set out in greater detail in the Act of 28 June 2006, codified in the Environment Code.

The French nuclear industry has developed a 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 final waste for disposal.

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

Since promulgation of the 2006 Act, to enable control of the 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.

These reports are available:

• CEA report - Informations relatives aux opérations portant sur des combustibles usés ou des déchets radioactifs en provenance de l'étranger - updated 31 December 2013;

AREVA report - Traitement des combustibles usés provenant de l'étranger dans les installations d'AREVA NC La Hague - updated 31 December 2013.

| Changes since the 2012 edition

The differences noted between the amounts of waste in existence at the end of 2010 and those in existence at the end of 2013 are due not only to the current production of waste, but also to:

 the decision to treat the spent fuel from reactor EL4 (Brennilis), previously considered as waste;

• a change in the packaging assumptions for bituminised sludge drums at Marcoule, resulting in an increase in the volume of conditioned ILW-LL. However, this change does not amount to an increase in the quantity of radioactive waste;

 a change in the packaging assumptions for radium-bearing waste from monazite processing, resulting in an increase in the volume of conditioned LLW-LL. However, this change does not amount to an increase in the quantity of radioactive waste;

 the inclusion of KDU (sludge from washing UF6 containers) from Pierrelatte, which contributes to the increase in the volume of LLW-LL;

the improvement of processing and conditioning;

• characterisation efforts that have enabled waste to be put in the correct category.

A summary of the main changes as compared with the 2012 edition of the National Inventory and for each management system is set out hereinafter.

For HLW (high-level waste) 1

The changes in stock levels of HLW at the end of 2013 correspond mainly to the current production of waste generated by the vitrification of solutions containing fission products generated from spent fuel processing at the AREVA NC plant at La Hague.

In previous editions, all the waste on French soil, including waste from outside France, was declared in the National Inventory, but only French waste was included in the statements. In this chapter, the statements include all the waste on French soil, hence the increase in volume above production levels.

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

The volume in stock at the end of 2013 was about 4,000 m³ greater than the stocks at the end of 2010, as set out in the 2012 edition.

In addition to the current production of ILW-LL, this increase is mainly due to:

the inclusion of all waste on French soil, including waste from outside France, as was the case with high-level waste;

changes in the packaging assumptions concerning the drums used by waste producers, which have led to an increase in volume. The option of re-conditioning all the bituminised waste packages from CEA operations in 380-litres containers has, for example, led to a increase of about 3,300 m³ in the total volume of this waste family.

It should also be noted that some waste categorised as ILW-LL in the 2012 edition has been transferred to the LLW-LL category as a result of progress made with the LLW-LL project. Some of the solid operating waste packages cemented in fibre-reinforced concrete containers at the La Hague plant are an example of this; the volume of these has been reduced by about 1,600 m³.

For LLW-LL (low-level long-lived waste) 3

The volume of LLW-LL has risen by about 4,400 m³ since the previous edition of the National Inventory.

This big increase is mainly due to the following reasons:

the current production of waste in this category is about 700 m³;

• the new assumptions adopted by Solvay for conditioning radiumbearing waste and standard solid waste have led to an increase of about 3,000 m³ in the total volume;

• the categorisation as LLW-LL of some of the solid operating waste packages cemented in fibre-reinforced concrete containers at the La Hague plant, originally categorised as ILW-LL, has led to an increase of about 1,600 m³.

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

The increase in the volume of LILW-SL at the end of 2013 is mainly due to the three extra years of operation of the reactor units and to the dismantling operations carried out during this period. Other changes observed in the conditioning assumptions made by waste producers have led to changes of the as disposed volume.

For VLLW (very-low-level waste)

By comparison with the figures as at the end of 2010, we note an increase of about 77,000 m³ in the volume of VLLW at the end of 2013, mainly due to dismantling operations.

For waste without a specific disposal solution 6

An item of waste without disposal solutions is defined as an item of waste for which none of the existing or planned disposal solutions can be used in the current state of our knowledge, mainly on account of its specific physical or chemical characteristics. As that knowledge is something that naturally evolves, and as hazard levels are assessed mainly on the basis of feedback from experience, conditions of acceptance for a disposal solution can change over time. Thus certain types of waste currently seen as not having any disposal solutions could subsequently be included in one of the various waste management categories.

Monitoring of the development and introduction of treatment processes is carried out under the National Radioactive Materials and Waste Management Plan.

The increase in the volume of waste without a specific disposal solution is due to the discovery of new waste during the dismantling of nuclear facilities.



For the waste from the AREVA plant in Malvési

Increase in the volume of waste from the AREVA plant in Malvési is due to three extra years of production of uranium conversion treatment residues.

The 2013-2015 National Radioactive Materials and Waste Management Plan (PNGMDR) states that it would be premature to consider only one solution for managing the waste generated by the AREVA plant in Malvési, and that a distinction should be made between the long-term management of waste already produced and the management of waste that will be produced between now and 2050. The AREVA plant in Malvési should therefore continue looking at:

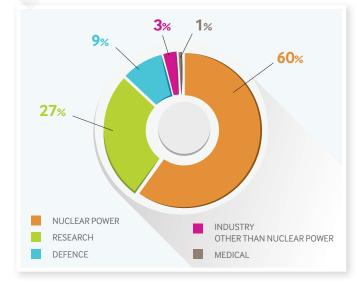
• the characterisation of the waste already produced and the mining residues in settling ponds B3 to B6, to provide more detail in the radiological and chemical inventory of waste to be managed;

feasibility studies of the subsurface disposal options for the waste already produced, checking in particular that a sufficient depth and volume exist for the potential disposal of this waste in satisfactory conditions.

BREAKDOWN OF RADIOACTIVE WASTE BY ECONOMIC SECTOR AT THE END OF 2013

| By economic sector at the end of 2013

The breakdown of radioactive waste at the end of 2013 is shown in the figure below for each economic sector.



BREAKDOWN OF THE TOTAL VOLUME OF WASTE BY ECONOMIC SECTOR

1 Nuclear power

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.

2 Research

The research sector corresponds mainly to the waste generated by the CEA particularly in civil nuclear, and to a lesser extent to the waste generated within the framework of research carried out on sites other than those of the CEA, e.g. the European nuclear research site at Prévessin (CERN), the Institut Laue-Langevin (ILL) in Grenoble and the large-scale heavy ion accelerator (GANIL) in Caen.

The radium-bearing waste generated during the work to clean up the former uranium ore treatment plant at Le Bouchet operated by the CEA between 1946 and 1970 is allocated to this economic sector.

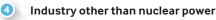
As explained above, the waste from Defence research activities is allocated to the Defence economic sector.

3 Defence

The waste allocated to the "Defence" economic sector brings together the waste stemming from the activities linked to the armed forces and to nuclear deterrents and 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 French national defence entities (DGA, Defence Medical Services, Army, Air Force and Navy, and Gendarmerie).

HLW and ILW-LL in this sector is generated solely by nuclear deterrent activities.



The waste generated by industrial companies using naturally occurring radioactive materials, and especially Solvay in the field of extraction of rare earth elements, is included in the "industry other than nuclear power" sector.

Lightning rods made between 1932 and 1986, gradually being removed and collected by Andra, are also included in this economic sector. It should be noted that ILW-LL allocated to the "industry other than nuclear power" sector corresponds to the "source blocks" containing spent sealed sources.



Lastly, the medical sector brings together the waste stemming from therapeutic and medical diagnostic activities, together with the waste generated by research in the medical field. Most of this waste has already been collected and disposed of by Andra.

BREAKDOWN OF THE TOTAL VOLUME OF WASTE BY ECONOMIC SECTOR AND MANAGEMENT METHOD

Volume (m ³) at the end of 2013	Nuclear power	Research	Defence	Industry other than nuclear power	Medical
HLW	2,700	190	230	-	-
ILW-LL	26,000	10,000	6,200	170	-
LLW-LL	42,000	20,000	17,000	12,000	2
LILW-SL	580,000	200,000	61,000	22,000	8,500
VLLW	220,000	160,000	42,000	11,000	3
DSF	2,400	740	650	4	1
Grand total	880,000	390,000	130,000	45,000	8,500

RADIOLOGICAL CONTENT OF RADIOACTIVE WASTE AT THE END OF 2013

Concerning **VLLW and LILW-SL**, 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 or evaluations using calculations. After checking conformity, Andra authorises their disposal. Apart from a few exceptions, the radioactivity of the waste shown in the Catalogue of Families is evaluated on the basis of the declarations, which have been kept since the disposal sites were put into service.

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

The total radioactivity is determined by calculating the decay up to 2013. These calculations are made by Andra using data provided by the waste producers.

The total radioactivity declared by the producers and shown in the Geographical Inventory is about 240,000,000 TBq, whereas the calculated total radioactivity is 230,000,000 TBq.

The difference between these two figures is due to the fact that, for simplicity, the radioactivity is declared by the waste producers on the date of production and often fails to take account of the natural decay of the radionuclides or generally of the daughter radionuclides in secular equilibrium.

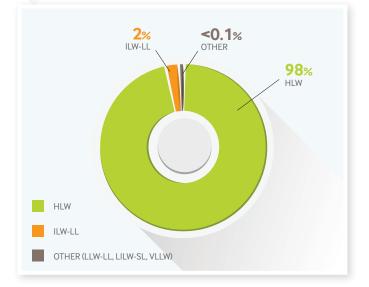
The table and chart summarise the calculated total radioactivity of the stocks of waste.

The radiological content consists of three types of radionuclides: radionuclides producing alpha radiation, those producing short-lived beta-gamma radiation and those producing long-lived beta-gamma radiation. The evaluated radioactivity of all the waste generated at 31 December 2013 is shown in the table below.

CALCULATED RADIOACTIVITY AT 31 DECEMBER 2013

Category	Radioactivity at the end of 2013 in TBq (10 ¹² Bq)
HLW	220,000,000
ILW-LL	5,500,000
LLW-LL	19,000
LILW-SL	36,000
VLLW	8
Total	~ 230,000,000

CALCULATED RADIOACTIVITY AT 31 DECEMBER 2013



DEFINITION

- Alpha (α) radiation: emission of a helium nucleus (consisting of 2 protons and 2 neutrons), also known as an "α particle".
- Beta (β) radiation: transformation of a neutron into a proton accompanied by the emission of an electron.
- Gamma (γ) radiation: emission of electromagnetic radiation, similar to visible light or X-rays.

	α (TBq)	Short-lived β/γ (TBq)	Long-lived β/γ (TBq)	Total radioactivity (TBq)
HLW	3,500,000	210,000,000	350,000	220,000,000
ILW-LL	44,000	4,300,000	1,100,000	5,500,000
LLW-LL	720	16,000	2,800	19,000
LILW-SL	910	27,000	8,300	36,000
VLLW	3	4	1	8

EVALUATED RADIOACTIVITY LEVELS OF THE WASTE AT THE END OF 2013

This radioactivity evaluation at 31 December 2013 shows that:

HLW accounts for 98% of total radioactivity of the radioactive waste present at 31 December 2013. This is waste extracted from spent fuel (fission products and minor actinides generated in reactors). The main radionuclides accounting for the radioactivity are:

- for the alpha radionuclides: curium-244 and americium-241,
- for the short-lived beta-gamma radionuclides: caesium-137, metastable barium-137, strontium-90 and yttrium-90.

The long-lived beta-gamma radionuclides account for less than 1% of the radioactivity.

• ILW-LL accounts for 2% of 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) account for over 90% of the total radioactivity of ILW-LL. 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 metastable 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, yttrium-90, caesium-137, metastable barium-137, tritium and cobalt-60 for the short-lived types, and nickel-63 for the long-lived types;

■ LLW-LL accounts for 0.01% of 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, uranium, etc.); ;

LILW-SL accounts for 0.02% of total radioactivity. The solid technological waste from the AREVA plant at La Hague 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, are the most active waste families in the LILW-SL inventory.

FORECAST QUANTITIES OF RADIOACTIVE WASTE STOCKS BY THE END OF 2020, THE END OF 2030 AND AT END OF ALL FACILITIES SERVICE LIFE

As explained in the introduction to this chapter, forecasts for waste generation by all facilities licensed as at the end of 2013 are declared by the producers.

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.

To evaluate the forecasts for end-2020, end-2030 and end of facility

life for the current edition of the National Inventory, the assumptions adopted in the producers' industrial scenarios are as follows:

- nuclear power production continues,
- all reactors have a 50-year service life;

• the dismantling of the GCR reactors has started and graphite LLW-LL is being generated by 2025 in connection with the future availability of the LLW-LL disposal facility. It should be noted that the dismantling of first-generation facilities is in progress and waste (LILW-SL and VLLW) is being generated by this. Some of this waste has already been sent to surface disposal facilities;

 all spent fuel is treated in accordance with the current management policy. By convention this assumes that the current fuel reprocessing plants will operate for long enough to do this. It also assumes that separated materials will be reused in current nuclear power plants or future plants;

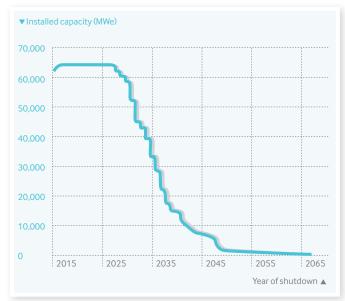
approximately 1,000 tonnes of spent fuel will be treated each year.

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

Dismantling work on PWRs currently operating will not begin before 2030. In the same way, dismantling of the UP2-800 and UP3 fuel reprocessing plants at La Hague is envisaged by AREVA after 2030.

At the end of 2030, dismantling work will be under way on some of the 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 ASSUMING A UNIFORM SERVICE LIFE OF 50 YEARS



| By category

These forecasts have changed as compared with those made since 2007 in successive editions of the National Inventory. The changes depend heavily on the industrial scenarios, particularly as regards the service life of the reactors.

AT THE END OF 2020

Category	Forecasts made in 2007	Forecasts made in 2010	Forecasts made in 2013
HLW	3,700	4,000	4,100
ILW-LL	47,000	45,000	48,000
LLW-LL	115,000	89,000	92,000
LILW-SL	1,000,000	1,000,000	1,000,000
VLLW	630,000	760,000	650,000
Grand total	~1,800,000	~1,900,000	~1,800,000

AT THE END OF 2030

Category	Forecasts made in 2007	Forecasts made in 2010	Forecasts made in 2013
HLW	5,100	5,300	5,500
ILW-LL	51,000	49,000	53,000
LLW-LL	152,000	133,000	120,000
LILW-SL	1,200,000	1,200,000	1,200,000
VLLW	870,000	1,300,000	1,100,000
Grand total	~ 2,300,000	~ 2,700,000	~ 2,500,000

The changes in the forecast quantities of HLW and ILW-LL at the end of 2020 and the end of 2030 are partly explained by the reasons for the change in stocks of waste at the end of 2013, i.e. a change in the packaging assumptions for bituminised sludge drums at Marcoule, resulting in an increase in the volume of conditioned ILW-LL. However, this change does not amount to an increase in the quantity of radioactive waste.

The reduction in the forecast for LLW-LL by the end of 2030 is due to the schedule being updated for the dismantling of nuclear facilities, particularly the GCRs, linked to the availability of the future LLW-LL disposal facility.

AT THE END OF FACILITY LIFE

Category	Forecasts made in 2013
HLW	10,000
ILW-LL	72,000
LLW-LL	180,000
LILW-SL	1,900,000
VLLW	2,200,000
Grand total	~ 4,300,000



The forecasts for end of facility life made at 31 December 2013 were declared for the first time in 2014, following legal publication of the order of 4 April 2014.

Concerning the waste from the AREVA plant in Malvési, for which long-term management methods are currently being defined, the forecasts are as follows:

FORECASTS MADE IN 2010		FORECASTS MADE IN 2013			
Category	For 2020	For 2030	Category	For 2020	For 2030
uranium conversion treatment residues	635,000	688,000	uranium conversion treatment residues	670,000	580,000

A heat treatment process for liquids containing nitrates is currently being developed, which explains the reduction in the forecast quantities at the end of 2030.

WASTE VOLUMES FROM DISMANTLING

As the nuclear industry is a relatively recent industry (dating back to the early 1960s), the main dismantling work on nuclear fuel cycle facilities and nuclear power plants is yet to come, and will take place mostly after 2030.

The waste from dismantling operations is of two types: conventional and radioactive. This distinction is made because basic nuclear installations have been divided into 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;

all waste from zones that could potentially generate nuclear waste is considered to be radioactive on principle, even if no radioactivity is detected in it.

1 Nature of the waste from dismantling

80% of the waste from dismantling is conventional waste, mainly rubble and metal, and 20% is radioactive waste. The radioactive waste is mostly very low-level waste and low-level short-lived waste:

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

In addition to this there is also some low-level long-lived waste, particularly graphite waste from the earliest reactors in France (gas-cooled graphite-moderated reactors) and a small amount of intermediate-level long-lived waste (activated waste, including metal parts from reactor cores and some waste from the ITER facility). The radioactive waste from dismantling is managed in the same way as waste from the operation of facilities. It is sorted and may be treated; it is then conditioned (see the special report on waste treatment and conditioning) before being stored or taken to a disposal facility appropriate to its level of radioactivity.

Estimation of the quantities of waste from dismantling

During preparations for dismantling operations, the quantities and types of waste that will be produced are evaluated as precisely as possible and the processing and conditioning methods to be used are defined. The evaluations take into account all the waste resulting from the operation, including any secondary waste, e.g. the volumes of effluent generated by decontamination.

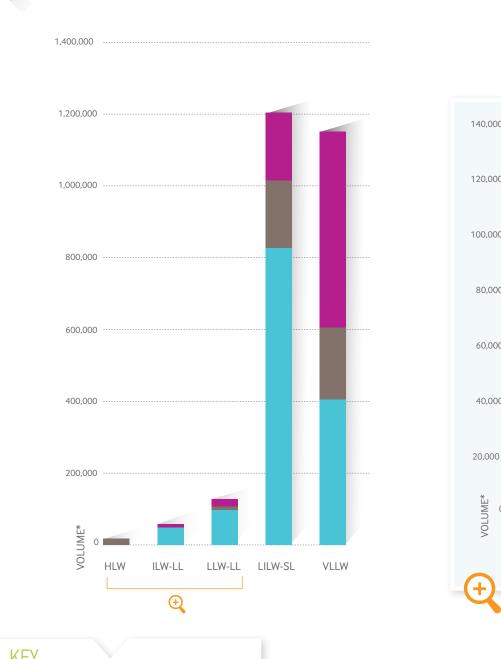
An exact inventory of the facilities to be cleaned up is therefore made first of all, including all the equipment they contain and their residual contamination level. A thorough knowledge of the facility's past activities is essential for this task.

The quantities of waste that will be produced by the dismantling of these facilities are then calculated using "technical ratios", established and regularly updated on the basis of feedback from experience of past dismantling operations. The ratios are used to calculate the quantity of waste resulting from the dismantling of each part of a facility, according to the nature and technical characteristics of that part and the radiological contamination measurements taken there.



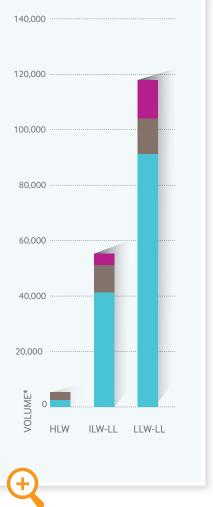
See also Report 3 on cleanup and dismantling.

The graph below shows the forecast quantities of waste at the end of 2030 for the various categories, distinguishing 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. The dismantling of the first generation gas-cooled graphitemoderated reactors will produce LLW-LL.



FORECAST QUANTITIES OF WASTE AT THE END OF 2030





2.2 RADIOACTIVE MATERIALS

A radioactive material is defined in Article L. 542-1-1 of the Environment Code as "a radioactive substance for which a subsequent use is planned or envisaged, where applicable after processing" (see Chapter 1).

Radioactive materials are not subject to any particular classification. They consist mainly of uranium (natural, enriched or depleted), fuels (new, in use or spent), separated uranium and plutonium from the treatment of spent fuels, and recovered materials from industries other than nuclear power (mainly materials containing thorium).

The following radioactive materials are presented in this chapter:

- natural uranium from mining activities;
- enriched uranium;
- uranium recycled from spent fuel after treatment;
- depleted uranium;
- thorium;
- suspended particulate matter (byproduct of the treatment of rare earth elements);

- fuel in use in nuclear power and research reactors;
- spent fuel awaiting treatment;
- plutonium obtained from spent fuel after treatment;
- fuel scrap.

Most of these materials are generated by the nuclear fuel cycle. In July 2010, the High Committee for Transparency and Information on Nuclear Safety (HCTISN) published a report that provides a detailed overview of the issues linked to the fuel cycle concerning recycling of radioactive materials.





UF₆ crystals



Background radioactivity

RADIOACTIVE MATERIAL STOCKS AT THE END OF 2013

| By category

The quantities of radioactive materials at the end of 2013, together with the sites on which they are stored, are shown below. 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 process used, the concentrates can take the form of uranates, known as *yellowcake* or uranium oxide (U_3O_8) . At 31 December 2013, about 26,000 tonnes of natural uranium were stored mainly on the AREVA sites in Malvési and Pierrelatte.

The natural uranium is then enriched to make nuclear fuel.

2 Enriched uranium

Enrichment consists in increasing the levels of uranium-235 (an energy-producing isotope whose content of 0.7% in natural uranium is too low) in order to obtain a material that can be used as fuel in light water nuclear power plants.

The enrichment process implemented since 2011 at the AREVA Georges Besse II plant on the Tricastin site is that of centrifugation.

The UF_6 gas is introduced into the cylinder rotating at very high speed, under vacuum, in a sealed housing.

The heaviest molecules are sent by the centrifugal force to the outside of the tube, while the lightest (²³⁵U) migrate towards the centre.

The gas enriched with the light isotope uranium-235 at the centre of the tube, rises. The gas enriched with the heavier uranium-238, sinks.

The enriched and depleted products are recovered at either end of the tube (top and bottom).

This elementary molecule separation stage is repeated within a number of centrifuges in series, known as cascades.

The enriched uranium used for electricity production contains about 4% uranium-235.

At 31 December 2013, just under 2,800 tonnes of enriched uranium were stored on the AREVA sites in Pierrelatte, Romans and Marcoule, and on various CEA sites.

3 Depleted uranium (Udep)

Enrichment provides uranium enriched in uranium-235 on the one hand, and depleted uranium on the other hand. Uranium depleted

of 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 2013, about 290,000 tonnes of depleted uranium (Udep) were stored in France, with just over 170,000 tonnes on the AREVA site at Tricastin, about 120,000 tonnes on the AREVA site in Bessines-sur-Gartempe, 500 tonnes on the AREVA site at Malvési and 150 tonnes on various CEA sites.

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. This flow represents about a hundred tonnes per year.

Furthermore, the stock of depleted uranium can be evaluated at 410,000 tonnes as at the end of 2030. This stock represents an abundant future resource for nuclear power production.

In a few years' time, developments in enrichment techniques, with centrifugation, should allow the re-enrichment of depleted uranium, under suitable economic conditions.

In addition, these stocks of depleted uranium could be recovered for use in the 4th generation fast neutron reactors, which could be deployed 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 thousand years.

Uranium recycled from spent fuel after recycling

Uranium extracted from spent fuel 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.

Recycled uranium 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).

Recycled uranium in France is owned mainly by the electricity utility EDF, and some is also owned by AREVA and CEA.

At 31 December 2013, 27,000 tonnes of recycled uranium were stored on the sites of Tricastin and La Hague. 2,700 tonnes belong to customers in other countries.



Thorium takes the form of thorium hydroxide or thorium nitrate. About 8,500 tonnes of heavy metal (tHM) are stored in France.

Within the framework of its treatment activities involving rare earth elements ores, Solvay 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 below);

• up to 1994, thorium nitrate, generated by treatment using the monazite nitrate method.

At 31 December 2013, about 6,300 tonnes of heavy metal (tHM) of thorium were stored in the form of nitrate and hydroxides on the site of the plant in La Rochelle.

There were also just under 2,300 tHM of thorium stored on the CEA site at Cadarache.

Lastly, a few tonnes of heavy metal of thorium owned by AREVA are stored on the sites at Bessines and Tricastin.

6 Suspended particulate matter

The suspended particulate matter (SPM) stemming from the process of neutralisation of the chemical effluents generated at the Solvay plant contains an average level of 25% of rare earth element oxides that are recoverable byproducts.

At 31 December 2013, about 5 tHM of SPM, a byproduct from the treatment of rare earth elements, were stored on the site of the plant at La Rochelle.

In the 2012 edition, the quantities of SPM were expressed in tonnes. To quantify the recoverable part more accurately, quantities of SPM are now expressed in tonnes of heavy metal (tHM): this unit represents the quantity of uranium, plutonium or thorium.

Nuclear fuels

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

These stocks are considered by their owners to be 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 (24 licensed 900 MWe reactors),
- fuel from the Phénix and Superphénix fast neutron reactors, which is no longer used (the reactors have been decommissioned),
- fuel belonging to the civil CEA, which is used in specific reactors for research purposes. They are more varied in form and physicochemical composition than EDF fuel. The quantity is also much smaller,
- fuel for defence entities in France, which is used either in reactors designed to make materials for nuclear deterrent weapons, or in the reactors on board submarines and ships, together with their prototypes on land.

EDF's strategy consists in processing the fuel with enriched natural uranium oxide. Treatment of ERU and MOX fuels will have started by 2040.

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.

RECYCLING OF SUSPENDED PARTICULATE MATTER AND CRUDE THORIUM HYDROXIDE Recycling of these materials is being studied by AREVA and SOLVAY.

The recycling of suspended particulate matter concerns its rare earth element, thorium and uranium content.

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

The thorium could be reusable in nuclear applications.

Although it is not yet deployed industrially, there is potential for reusing thorium in sectors other than nuclear power:

• in the medical field for cancer treatment using alpha radio-immunotherapy, lead-212 generated by the decay 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.

EXAMPLE OF THE USE OF THORIUM-BEARING MATERIALS BY AREVA MED

AREVA Med is the medical subsidiary of AREVA. It was created in 2009 and focuses on the development of new targeted therapies for cancer treatment.

AREVA Med has developed a process for extracting lead-212 (²¹²Pb), which is now used in the Maurice Tubiana laboratory. The therapeutic field in which AREVA Med is working is known as alpha therapy or alpha radioimmunotherapy, where ²¹²Pb is combined with the use of an antibody that can recognise and destroy the cancer cells, limiting the impact on the surrounding healthy cells. At the end of 2014, AREVA Med finished recruiting patients with peritoneal cancers for the world's first clinical trial using ²¹²Pb.

Alpha therapy has been known about for several years, but the development of treatments has been held back by the scarcity of alpha-emitting isotopes and the technical difficulties of producing and purifying these isotopes for medical use. AREVA has a thorium nitrate source consisting mainly of ²³²Th, and AREVA Med is reusing this to produce ²¹²Pb compatible with the requirements of developing new treatments in the long term.



Fuel before use

The following fuels were awaiting use at nuclear power plants and research reactors in France at 31 December 2013:

- about 440 tHM of UOX fuel at the19 PWR nuclear power plants in France,
- about 38 tHM of MOX fuel at the PWR nuclear power plants at Blayais, Chinon, Dampierre and Gravelines;

Fuel in use in nuclear power and research reactors

The following quantities of fuel were in use in French nuclear power plants in France at 31 December 2013:

- about 4,300 tHM of UOX fuel in the 19 PWR nuclear power plants in France,
- 200 tHM of ERU fuel in the four reactors of the nuclear power plant in Cruas,
- about 410 tHM of MOX fuel in the following PWR nuclear power plants: Blayais, Chinon, Dampierre, Gravelines, Saint-Laurentdes-Eaux B and Tricastin.

Spent fuel awaiting processing

The following quantities of fuel were stored awaiting processing at the end of 2013:

- spent UOX fuel: 12,000 tHM in total, with 3,700 tHM on the sites of the 19 PWR nuclear power plants in France, and about 8,200 tHM on the site at La Hague. 30 tHM of fuel from outside France are also stored on the site at La Hague,
- spent ERU fuel: 110 tHM on the site of the nuclear power plant in Cruas, together with about 310 tHM on the site at La Hague,
- spent MOX fuel: 340 tHM on the sites of the following PWR nuclear power plants: Blayais, Chinon, Dampierre, Gravelines, Saint-Laurent-des-Eaux and Tricastin, together with 1,200 tHM on the site at La Hague,
- spent FNR fuel: 105 tHM of spent FNR fuel from the Superphénix reactor on the site at Creys-Malville, 38 tHM of spent FNR fuel from the Phénix reactor at the sites at Marcoule and La Hague,
- spent oxide fuel from civil research reactors: 57 tHM on CEA sites and 5 tHM on the site at La Hague,
- spent metal fuel from the experimental CEA reactors and GCR reactors: 15 tHM on CEA sites and 4 tHM on the site at La Hague,
- spent fuel from nuclear propulsion: about 156 tonnes.

8 Plutonium extracted from spent fuel by processing

The plutonium contained in spent fuel assemblies is extracted from them during their processing. Spent uranium fuel of the light water type currently contains about 1% 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 the 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.

Nowadays, plutonium is used to make MOX fuel, which contains depleted uranium and plutonium in the form of oxide (U,Pu)O₂ powder pellets. In France, 24 reactors are now licensed to use MOX fuel.

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 those countries.

At 31 December 2013, just over 52 tonnes of plutonium were stored in France, including:

• 41 tonnes of plutonium stored at the AREVA NC plant at La Hague, of which 16 tonnes belong to customers outside France;

- 9 tonnes of plutonium currently being used in the MOX fuel manufacturing process (in the form of PuO₂, mixed oxide (U,Pu)O₂ and in finished MOX fuel assemblies), including one tonne belonging to customers outside France;
- about two tonnes of plutonium stored in various CEA facilities.

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



There were 234 tonnes of non-irradiated mixed uranium-plutonium fuel scrap awaiting reprocessing on the site at La Hague at the end of 2013. This scrap was counted in the uranium and plutonium categories in the previous edition. There is no non-irradiated uranium fuel scrap awaiting reprocessing.



The new Superphénix core is the fuel that should eventually have replaced the fuel used when the plant was in operation. Because Superphénix has now been decommissioned, this fuel has never been used and has therefore not been irradiated. This new Superphénix core, which represents 72 tHM, is currently stored on the Creys-Malville site.



Carousel of plutonium drums



Fuel rods

THE RADIOACTIVE MATERIALS AT THE END OF 2013 ARE SHOWN IN THE TABLE BELOW

UOX fuel before use	440
UOX fuel in use in nuclear power plants	4.400
Spent UOX fuel awaiting treatment	12,000
ERU fuel before use	
ERU fuel in use in nuclear power plants	200
Spent ERU fuel awaiting treatment	420
Mixed uranium-plutonium fuel before use	38
Mixed uranium-plutonium fuel in use in nuclear power plants	410
Spent mixed uranium-plutonium fuel awaiting treatment	1,500
Non-irradiated mixed uranium-plutonium fuel scrap awaiting treatment	230
Non-irradiated uranium fuel scrap awaiting treatment	-
Spent FNR fuel awaiting processing	150
Research reactor fuel before use	0.2
Fuel in use in research reactors	0.2
Other civil spent oxide fuels	57
Other civil spent metal fuels	19
Plutonium from spent fuel after treatment, in all physicochemical forms	52
Natural uranium from mining activities, in all physicochemical forms	26,000
Enriched natural uranium, in all physicochemical forms	2,800
Enriched uranium from spent fuel treatment, in all physicochemical forms	-
Uranium from spent fuel treatment, in all physicochemical forms	27,000
Depleted uranium, in all physicochemical forms	290,000
Thorium, in the form of nitrates and hydroxides	8,500
Suspended particulate matter (byproduct of the treatment of rare earth elements)	5
Other materials	72
Spent fuel from the national Defence entities	156 t

* Rounded figures.

| By economic sector

The breakdown of radioactive materials is as follows:

Economic sector	Quantity (tHM)*
Nuclear power	360,000
Research	300
Industry other than nuclear power	8,600
Medical	15
Defence	156 t

* Rounded figures.



The quantities of depleted uranium have been taken into account in the table above, and were not in the Essentials 2015 edition of the National Inventory.

The **nuclear power** sector includes all the radioactive materials connected with UOX, MOX and ERU fuels (19,659 tHM), whether

they are unused, in use or awaiting treatment or in the form of scrap, together with plutonium (52 tHM), a few tonnes of thorium (4 tHM) and uranium in all physicochemical forms except for depleted uranium (55,670 tHM). The new Superphénix core is counted in this sector (72 tHM).

The radioactive materials in the **research** sector are the fuel for research reactors before use (0.18 tHM) or during use (0.20 tHM) in the research reactors, and other civil spent oxide fuel (57 tHM) or spent metal fuel (19 tHM). This sector also includes some plutonium (2 tHM) and some uranium in all physicochemical forms except depleted uranium (27 tHM). The Phénix fuel awaiting treatment (43 tHM) is also included in this economic sector.

The **defence** sector consists only of the spent fuel from national Defence entities (156 t).

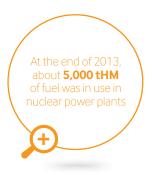
Industry other than nuclear power concerns only residues from the treatment of ores and byproducts containing a significant amount of thorium (8,500 tHM) and uranium (89 tHM). The suspended particulate matter in its present state still contains radioactive materials (5 tHM).

The **medical** sector possesses depleted uranium only for radiological protection (15 tHM).

FORECAST QUANTITIES OF RADIOACTIVE MATERIALS STOCKS IN 2020 AND 2030

The radioactive materials as at the end of 2013, 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 waste.



1

RADIOACTIVE MATERIALS AT THE ENDS OF 2013, 2020 AND 2030 (HMt)*			
Material	2013	2020	2030
UOX fuel before use	440	440	420
UOX fuel in use in nuclear power plants	4,400	4,600	3,700
Spent UOX fuel awaiting treatment	12,000	11,000	11,000
ERU fuel before use	-	-	20
ERU fuel in use in nuclear power plants	200	-	290
Spent ERU fuel awaiting treatment	420	530	1,200
Mixed uranium-plutonium fuel before use	38	45	45
Mixed uranium-plutonium fuel in use in nuclear power plants	410	490	390
Spent mixed uranium-plutonium fuel awaiting treatment	1,500	2,500	3,900
Non-irradiated mixed uranium-plutonium fuel scrap awaiting treatment	230	240	200
Non-irradiated uranium fuel scrap awaiting treatment	-	-	-
Spent FNR fuel awaiting processing	150	150	100
Research reactor fuel before use	0.2	0.2	0.3
Fuel in use in research reactors	0.2	0.1	0.1
Other civil spent oxide fuels	57	57	57
Other civil spent metal fuels	19	19	20
Plutonium from spent fuel after treatment, in all physicochemical forms	52	33	39
Natural uranium from mining activities, in all physicochemical forms	26,000	25,000	25,000
Enriched natural uranium, in all physicochemical forms	2,800	960	960
Enriched uranium from spent fuel treatment, in all physicochemical forms	-	-	-
Uranium from spent fuel treatment, in all physicochemical forms	27,000	34,000	44,000
Depleted uranium, in all physicochemical forms	290,000	330,000	410,000
Thorium, in the form of nitrates and hydroxides	8,500	8,500	8,400
Suspended particulate matter (byproduct of the treatment of rare earth elements)	5	3	-
Other materials	72	72	72
Spent fuel from the national Defence entities	156 t	212 t	271 t

2.3 PLANNING SCENARIOS

The purpose of this section is to provide a prospective overview of the waste and materials that would be generated by all the facilities licensed at the end of 2013 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.

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SCENARIO

ONGOING PRODUCTION OF NUCLEAR POWER

This scenario is based on two assumptions: electricity continues to be produced in nuclear power plants and the current strategy for spent fuel reprocessing is maintained. The average service life of all reactors is assumed to be 50 years, with a guaranteed total maximum capacity for nuclear power production of 63.2 GWe. The assumption is also made that all fuel consumed by reactors licensed at the end of 2013 is treated to separate the materials (uranium, plutonium) from the final waste. No spent fuel is directly disposed of and all the plutonium extracted from spent fuels is recycled in current or future reactors, in the form of mixed uranium and plutonium oxide fuel.

Given the number and age of the reactors currently licensed to use this type of fuel, the nuclear power plants in existence today will be able to use separated plutonium until approximately 2029. Beyond that, the rate at which spent fuel is reprocessed and therefore the rate of plutonium production will depend directly on the rate at which new reactors consuming this fuel are commissioned. The spent fuels (UOX, MOX) produced by existing power plants until the end of their life would represent about 30,000 tHM to be recycled.

SCENARIO 2

NON-RENEWAL OF NUCLEAR POWER PRODUCTION FACILITIES

This scenario assumes that existing nuclear power plants are not replaced, so the treatment of spent fuel would stop before the reactors are shut down, to avoid being left with separated plutonium. It also assumes a 40-year reactor service life. Plutonium recycling is limited to the MOX fuel fabrication necessary for the operation of the reactors currently licensed to use this type of fuel. Based on the decommissioning dates for these reactors, plutonium separation through the treatment of spent fuel would cease to be necessary from 2019.

In this scenario, about 28,000 tHM of spent fuel, UOX and MOX, would become waste and would have to be disposed of in a deep geological formation.

Both of the planning scenarios, defined by the National Inventory steering committee, complement the industrial scenarios used by the producers for their forecasting to end-2020, end-2030 and end of facility life.

They take account of an installed nuclear power capacity limited to 63.2 GWe, in accordance with the draft legislation on energy transition for green growth, but they differ as regards the assumed service life of PWRs: 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 for 50 years as standard 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 both scenarios the producers have estimated the possible volumes of waste and quantities of materials generated by all the nuclear facilities until the end of their service life.

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

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

• there are 59 licensed nuclear power reactors: he 58 existing reactors and the EPR reactor being built on the Flamanville site that is scheduled to be put into service in 2017;

 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 tHM/year; the plutonium extracted during processing of spent fuel is recycled, in the form of MOX assemblies, at a rate of 120 tHM/year;

 the uranium recovered during processing of spent fuel is recycled in the form of ERU assemblies at a rate of 74 tHM/year; this tonnage is divided up between the four reactors at Cruas licensed to load this type of fuel;

• the waste linked to uranium conversion in the AREVA plant in Malvési is not taken into account in the estimations.

The assumptions set out above mean that an average of 1,200 tHM of PWR fuel would be unloaded per year (including 120 tHM of MOX type fuel).

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

SCENARIO 1: ONGOING PRODUCTION OF NUCLEAR POWER

This scenario assumes that all spent fuel will be treated, including that from the Brennilis reactor, and hence the treatment activities will continue on the basis of about one thousand tHM of fuel per year.

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. It does not involve any presumptions as to the quantities of radioactive materials and waste generated by these new reactors because they were not licensed on 31 December 2013.

The assumption of a uniform service life of 50 years for all 59 reactors would lead to them being shut down definitively between 2027 and 2067.

The cumulative quantity of PWR fuel unloaded would then be close to 64,000 tHM (58,000 tHM of UOX, 4,000 tHM of MOX and 2,200 tHM of ERU).

The treatment flows adopted (1,000 tHM of UOX per year) balance out the plutonium recycling flows while the existing MOX-enabled reactors 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 MOX-enabled reactors and the quantities of plutonium constituting 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 tHM 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 tHM of PWR fuel would then remain to be processed, together with the 180 tHM of FNR fuel from the Superphénix reactor.

The material will be separated progressively (as is currently the case) to meet the actual fuel requirement 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 allow a methodology to be established for estimating the overall quantities of radioactive materials and waste generated by a given number of nuclear power facilities (*see box on next page*).

SCENARIOS FOR THE DEVELOPMENT OF FUTURE REACTORS

The CEA, AREVA and EDF have set up a working group tasked with proposing scenarios for the inclusion of sodium-cooled fast reactors among the existing facilities, based on the assumption of a nuclear power generation capacity of 420 terawatt hours/year, and gradual replacement of the existing PWRs when they reach the end of their life with EPRs with the same rated capacity during 2030-2060.

Four possible configurations for facility renewal have been proposed which would allow the gradual introduction of fast neutron reactors. They aim to make the best possible use of plutonium resources in order to save uranium and to stabilise the inventory of stored spent fuel. These configurations make use of the flexibility of fast neutron reactors, which can operate as isogenerator reactors, fast breeder reactors or burner reactors:

- the first configuration consists of deploying only EPRs, some of which would probably consume MOX or ERU fuel;
- the second configuration would deploy a few fast neutron reactors to stabilise the inventory of spent MOX fuel;
- the third configuration would aim to stabilise the plutonium inventory by using fast neutron reactors for the multiple recycling of fuel;

• finally, the aim of the last configuration would be to not require any more natural uranium. The only reactors would be fast neutron reactors and EPRs consuming MOX fuel.

These studies confirm that the transition can only be achieved at constant power levels and generation capacity by making successive changes to the configuration of nuclear power generation facilities. The operating periods of each configuration and the rates of reactor construction are still to be determined.

SCENARIO 2: NON-RENEWAL OF NUCLEAR POWER PRODUCTION FACILITIES

Conversely, 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 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 of ongoing nuclear power production.

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 2057).

The cumulative quantity of PWR fuel unloaded would hence be something like 52,000 tHM (48,000 tHM of UOX, 2,800 tHM of MOX and 1,400 tHM 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 MOX-enabled reactors until the end of their service life would be reached in about 2018 or 2019, i.e. after treatment of 24,000 tHM 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 tHM), into waste for direct disposal.

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

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 recycled uranium 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 tHM of spent fuel).

A summary of the waste generated under these scenarios is given in the table below.

PLANNING SCENARIOS: ESTIMATION OF WASTE

	Category	Ongoing production of nuclear power	Non-renewal of nuclear power production facilities
	Spent UOX & ERU fuel		~ 50,000 assemblies*
HLW	Spent FNR fuel		~ 1,000 assemblies*
ΠLΨΨ	Spent MOX fuel		~ 6,000 assemblies*
	Vitrified waste	10,000 m ³	3,900 m ³
ILW-LL		72,000 m ³	65,000 m ³
LLW-LL		180,000 m ³	180,000 m ³
LILW-SL		1,900,000 m ³	1,800,000 m ³
VLLW		2,200,000 m ³	2,100,000 m ³

in m³ as disposed

* 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 m³, these assemblies represent a gross volume of about 12,000 m³.

Andra checked the feasibility of deep disposal of spent fuel in 2005. The disposal conditioning concepts used for the demonstration produced a disposal package volume of about 89,000 m² (about eight times more than the unconditioned volume).

2.4 **STORAGE AND DISPOSAL SITES** FOR RADIOACTIVE MATERIALS AND WASTE

Storage of radioactive materials or waste is defined in Article L. 542-1-1 of the Environment Code 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.

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STORAGE OF RADIOACTIVE WASTE

Article 3 of the Order of 9 October 2008 requires producers to declare to the National Inventory a certain amount of information concerning storage facilities designed to accommodate radioactive waste packages for which definitive management solutions do not exist or are at the planning stage.

The 2013-2015 National Radioactive Materials and Waste Management Plan (PNGMDR) lists all the studies and research being

carried out 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 49 lists these licensed storage sites as at the end of 2013, with their levels of occupation for the sites in use; the table below shows the planned extensions for some of the storage sites.

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

Declaring entity	Site	Waste packages for which the storage facility is designed	Date of commission- ing of the extension	Total storage capacity (number of packages)*
CEA	EIP ** (Marcoule)	Bituminised sludge packages	2019	4,235
CEA	INB 164-CEDRA (Cadarache)	500 l and 870 l packages, 500 l concrete packages for filtration sludge	2025	7,500

PLANNED EXTENSIONS FOR STORAGE SITES

*Capacity shown in m³.

**The CEA reference scenario calls for conditioning of ILW-LL in disposal packages in Marcoule beginning in 2017, followed by intermediate storage prior to shipment to Cigeo when it is commissioned. A backup scenario plans for the opening of an extension of the EIP storage facility early in 2017.

STORAGE SITES LICENSED AS AT THE END OF 2013

Declaring entity	Site	Waste packages for which the storage facility is designed	Date of commis- sioning	Total storage capacity (number of packages)	Storage capacity in use (number of packages)	Level of occupation
AREVA NC	CEZUS (Jarrie)	Drums of radium-bearing residues	2005	3,538*	2,360*	67%
AREVA NC	ES BUILDING (La Hague)	Bituminised sludge packages	1995	27,000	0	0%
AREVA NC	S BUILDING (La Hague)	Bituminised sludge packages	1987	20,000	11,535	57%
AREVA NC	ECC (La Hague)	CSD-C packages	2002	20,800	12,812	62%
AREVA NC	EDS/ADT2 (La Hague)	CBF-C'2 packages	2008	2,759	750	27%
AREVA NC	EDS/EDC-A (La Hague)	Cemented hull and end cap packages	2009	1,119	492	44%
AREVA NC	EDS/EDC-B and EDC-C (La Hague)	Cemented hull and end cap packages	1990	1,656	1,518	92%
AREVA NC	EDS/EDT (La Hague)	CBF-C'2 and CAC packages	1990	6,512	5,649	87%
AREVA NC	EEV/SE (La Hague)	CSD-V and CSD-B packages	1996	4,428	4,395	99%
AREVA NC	EEV/LH (La Hague)	CSD-V and CSD-B packages	2013	4,199	387	9%
AREVA NC	R7 (La Hague)	CSD-V and CSD-B packages	1989	4,500	4,419	98%
AREVA NC	T7 (La Hague)	CSD-V packages	1992	3,600	3,599	100%
CEA	ICPE SOLVAY - buildings 420 and 465 (Cadarache)	Drums of radium-bearing residues	1992	26,800	25,323	94%
CEA	INB 164-CEDRA (Cadarache)	500 I and 870 I packages, 500 I concrete packages for filtration sludge	2006	9,000	2,818	31%
CEA	INB 56 (Cadarache)	Miscellaneous packages	1968	7,500*	6,240*	83%
CEA	AVM (Marcoule)	Vitrified waste packages (AVM), AVM operating waste packages	1978	3,800	3,468	91%
CEA	EIP (Marcoule)	Bituminised sludge packages	2000	4,235*	3,294*	78%
CEA	PIVER (Marcoule)	PIVER glass packages	1976	46*	13*	28%
CEA/ DAM***	Tritiated waste storage unit (Valduc)	Tritiated waste	1982	21,500	14,343	67%
EDF	ICEDA (Bugey)	Cemented packages	2017**	2,000	0	0%
SOLVAY	Chef-de-Baie plant (La Rochelle)	Radium-bearing waste	1988	56,980*	7,580*	13%

*Capacity shown in m³.

**ICEDA has existed administratively (INB 173) since the construction licence was obtained by decree of 23 April 2010, but the facility cannot go into operation until a licence has been obtained from the ASN, probably in 2017.

***The capacity of this storage site was increased at the end of 2012.

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DISPOSAL OF RADIOACTIVE WASTE

Andra operates three disposal facilities (*see Report 1*). The CSM waste disposal facility in northwest France is in a monitoring phase. The Cires waste collection, storage and disposal facility for VLLW and the CSA waste disposal facility for LILW-SL are currently in operation. At 31 December 2013 the fill factors of Andra's various disposal facilities are as follows:



DISPOSAL OF RADIOACTIVE WASTE

	Site	Category	Total disposal capacity (m³)	Capacity used (m ³)	Fill factor
Cires	Morvilliers	VLLW	650,000 m ³	250,000 m ³	38%
CSM	Digulleville	LILW-SL	530,000 m ³	530,000 m ³	100%
CSA	Soulaines-Dhuys	LILW-SL	1,000,000 m ³	280,000 m ³	28%

Figures are rounded to two significant figures.

STORAGE OF RADIOACTIVE MATERIALS

Spent fuels

Spent fuel management begins with a period in storage in a pool. A depth of a few metres of water is enough to protect against the extreme radioactivity emitted by fuel assemblies recently unloaded from a reactor core. Water is also an excellent coolant, able to absorb the heat released by fuel assemblies, which is initially very intense.

Fuel assemblies are unloaded from the core underwater so that they are not in the open air at any time. They are stored in borated steel baskets in a pool located in the immediate vicinity of the reactor (the pool is also used for loading operations).

The aim of this precaution is to prevent any risk of criticality as, although the fuel assemblies are spent, the fuel still contains more fissile uranium-235 (approximately 1%) than natural uranium does. Neutron-absorbing boron is added to instantly shut down any chain reactions.

The length of this initial storage period and the operations that follow it depend on the intended purpose of the spent fuel.

In countries like France and Japan that have chosen to reprocess fuel, this storage period is between 12 and 18 months, to allow the radioactivity to decay sufficiently and enable enough heat to be released for the fuel to be transported to a reprocessing plant.

Fuel assemblies that are to be reprocessed are stored in very large pools after being transported to the plant at La Hague. The fuel is cooled in these pools for a minimum of five years. Fuel currently spends on average eight years in these pools in practice. After this cooling period, the fuel is processed to recover the uranium and plutonium it contains, and the residue is conditioned as vitrified waste.

Spent ERU and MOX fuel, which is not reprocessed as it is produced, is also grouped and stored in these pools. EDF plans to treat it later so that the separated materials can be reused in 4^{th} generation fast neutron reactors.

SPENT FUEL STORAGE IN OTHER COUNTRIES

In countries that do not treat their fuel, fuel assemblies initially continue to be stored in pools. In the US they remain at the 103 reactors where they were generated. Some pools are full or nearly full. After a period of time, the heat has decreased enough (to 470 watts per fuel assembly after 35 years) to allow them to be cooled simply by circulating air. The oldest fuel assemblies are removed from the pools to be stored dry, inside thick-walled casks that protect against radiation.

Sweden, which has only 12 reactors, has opted to centralise its fuel at a single site, and has built a large underground storage facility. Swedish fuel is earmarked for final disposal in a geological repository.

Germany is in an intermediate situation. Until 2005, Germany sent its spent fuel for treatment at La Hague and had to store the vitrified waste subsequently returned to it. Since 2005 it has also had to store its untreated spent fuel.

2 Depleted uranium

Depleted uranium comes in two possible forms, which are stored under conditions suited to their characteristics:

 UF₆ is generally stored as a solid, in cylindrical containers that meet very strict international regulations. This is because it is highly toxic in contact with the water vapour in air. The containers are designed to be stored in the open air. They are used in Russia, the US, the UK and Germany, and at Pierrelatte in France;

 U₃O₈ (which is very stable like natural uranium) is conditioned in sealed metal containers known as "green cubes", with an average capacity of about 7 tonnes of uranium. These containers are stored under buildings.

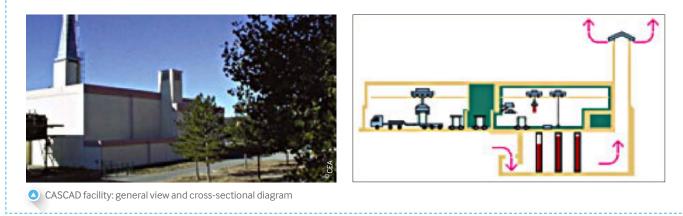
In France, to reduce "at source" the risks associated with storage, depleted uranium to be stored for a long period of time is stored as U_2O_0 (which has the advantage of being extremely stable).

3 Uranium obtained from treatment

Recycled uranium is generally conditioned as U_3O_8 in containers. These containers are stored in special buildings on the AREVA site at Tricastin.

CASCAD - AN EXAMPLE OF DRY STORAGE FOR SPENT FUEL

Dry storage facilities also exist in France. They are used to store fuel that will « never be used » (fuel from research reactors or fuel from R&D studies conducted by the CEA), at Marcoule or Cadarache, until a further management decision is made concerning this fuel. One example is the Cascad facility, a dry storage bunker at Cadarache. The facility has been in operation since 1990 and was designed to store irradiated nuclear fuel conditioned in steel containers for fifty years. In particular, it currently holds the irradiated fuel from the Brennilis power plant, and spent fuel from the Osiris experimental reactor. Besides its technical facilities for reception, checking and conditioning, the first part of the facility has a storage unit consisting of 319 shafts. These are cooled by the circulation of air through natural convection.







CHAPTER 3

DETAILED RESULTS

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3.	5 Medicine Radioactive waste statement at the end of 2013 Stock of radioactive materials at the end of 2013	75 75 75

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This chapter presents, for each of the economic sectors, the radioactive materials and waste listed 31 December 2013. As a reminder, the five economic sectors are defined as follows:

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FIVE ECONOMIC SECTORS



Nuclear power

This mainly includes nuclearpower 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 of a portion of the materials extracted from spent fuel).



Research

This includes civil nuclear research (in particular the Commission's research activities into atomic energy and alternative energies), medical research laboratories, nuclear and particle physics, agronomy, chemistry, biology, etc.



Defence

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



Industry other than nuclear power

This includes in particular the extraction of rare earths, the manufacture of sealed sources, as well as various applications such as weld inspection, the sterilisation of medical equipment, the sterilisation and conservation of food products, etc.



Medicine

This includes diagnostic (scintigraphy, radiotherapy, etc.) and therapeutic activities.



- The presentation adopted for each economic sector is as follows:
- description of the economic sector;
- statement of the existing volumes of radioactive waste at 31 December 2013 for the sector concerned; the detailed status per site of the stocks listed is presented in the Geographical Inventory available separately;
- stocks of radioactive materials as at 31 December 2013.

3.1 NUCLEAR POWER

This sector includes nuclear power plants, fuel cycle facilities, waste treatment and the maintenance of facilities in the sector.

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NUCLEAR POWER PLANTS (NPPs)

Reactors in operation

Currently France's nuclear power industry comprises 58 working nuclear reactors, located on 19 sites.

In France, the operating nuclear power plant fleet consists entirely of light water units, with 58 pressurised water reactors (PWRs) using enriched uranium commissioned between 1977 and 1999.

By 2017 another EPR-type pressurised water reactor (Flamanville) should complete the existing fleet.

The operation of EDF's nuclear power plants and related maintenance activities mainly generate VLLW and LILW-SL, as well as ILW-LL.

The processing of irradiated fuel in these plants produces HLW and ILW-LL.

ILW-LL produced during operation, mainly involves burnable poison rod assemblies (absorber rod assemblies whose role is to reduce core reactivity during the first operating cycle) and control rods (absorber rod assemblies in which the absorber rods slide inside the fuel assemblies to control reactor power).

The conditioning hypothesis adopted by EDF is to embed this metal waste in concrete containers with intermediate storage of the packages in a centralised facility (ICEDA). This new facility should be in operation by 2017 at the Bugey site (01).

ILW-LL produced during dismantling operations primarily implies metal structures which, like the rod clusters, display surface contamination associated with high activity in the mass.

LILW-SL and VLLW consists of equipment, filtration/purification residue (resins, filters, sludge, etc.), consumables (vinyl or cotton suits, etc.), as well as scrap parts (valves, tubes, etc.).

This waste has been contaminated by contact with fluids (reactor coolant, ventilation air, etc.) that carry fission products or activated corrosion products when they pass through the core.

LILW-SL produced by EDF is conditioned on-site at the power plants in concrete waste packages or in metal drums and container boxes, which are respectively compacted or injected at the CSA, with the

THE WASTE PRODUCED BY A PWR IN FIGURES

• A PWR produces on average about **220 m³** of radioactive waste per year (excluding fuel), mainly LILW-SL and VLLW, divided between **60%** LILW-SL and **40%** VLLW;

 Spent fuel processing, for one reactor, annually produces approximately 3 m³ of HLW and 4 m³ of ILW-LL;

• Dismantling: it is expected that the deconstruction of a PWR will produce on average **18,000 m³** of radioactive waste, this amount of waste varying according to the power of the reactor.

exception of incinerable waste and scrap iron that can be melted down, which is sent to Centraco plants.

VLLW produced by EDF varies in nature. This waste comes from "potential nuclear waste production areas" in the power plants displaying a very low level of radioactivity, in some cases, so low that it can hardly be measured. A part of this waste is generated by the dismantling of the oldest plants and by the operation of nuclear power plants (NPPs).

Major maintenance operations in nuclear power plants, in particular the replacement of steam generators and reactor vessel heads, produce voluminous waste. EDF considers steam generators as recoverable materials.

NUCLEAR POWER PLANT FUELS

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

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

However, 24 reactors are licensed to load mixed uraniumplutonium oxide (MOX) and four reactors are now equipped to use ERU type fuel made of enriched recycled uranium.

REACTORS IN OPERATION

Sites and dates of coupling to the network (first reactor - last reactor)	Number of reactors in operation - PWR series	Net power output per reactor in MWe*	Number of reactors licensed to load MOX fuel
Fessenheim - (04/1977 – 10/1977)	2	880	-
Bugey - (05/1978 – 07/1979)	4	910/880	-
Gravelines - (03/1980 – 08/1985)	6	910	6
Dampierre - (03/1980 – 08/1981)	4	890	4
Tricastin - (05/1980 – 06/1981)	4	915	4
Saint-Laurent-des-Eaux B - (01/1981 — 06/1981)	2	915	2
Blayais - (06/1981 – 05/1983)	4	910	4
Chinon B - (11/1982 – 11/1987)	4	905	4
Cruas - (04/1983 - 10/1984)	4	915	-
Paluel - (06/1984 – 04/1986)	4	1,330	-
Saint-Alban - (08/1985 – 07/1986)	2	1,335	-
Flamanville - (12/1985 – 07/1986)	2	1,330	-
Cattenom - (11/1986 – 05/1991)	4	1,300	-
Belleville - (10/1987 – 07/1988)	2	1,310	-
Nogent-sur-Seine - (10/1987 – 12/1988)	2	1,310	-
Penly - (05/1990 – 02/1992)	2	1,330	-
Golfech - (06/1990 – 06/1993)	2	1,310	-
Chooz B - (08/1996 – 04/1997)	2	1,455	-
Civaux - (12/1997 – 12/1999)	2	1,450	-
19 sites	58 reactors	-	24 reactors

* MWe: megawatts of electricity

2 Decommissioned reactors

EDF operated six former generation gas-cooled graphite-moderated reactors (GCRs) developed by the CEA and spread over 3 sites: the three reactors of Chinon, the two reactors of Saint-Laurent-des-Eaux and the reactor of Bugey. The dismantling of these reactors is under way and the resulting waste is included in this economic sector.

This series generated "graphite" LLW-LL in particular. 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, planned for 2025, which is linked to the availability of the future LLW-LL repository. On the other hand, the sleeves, which have been removed and are in storage in silos at the Saint-Laurent-des-Eaux site and at the Marcoule and La Hague sites, are already counted as waste. The conditioning hypothesis applied for this existing and future waste is cementation in 10 m³ concrete containers.

In addition, three reactors of three different types are also being dismantled. These are the first Chooz PWR, the Brennilis EL4 heavy water reactor and the fast neutron reactor at Creys-Malville.

57

DECOMMISSIONED REACTORS

Sites	Туре	Number of reactors
Chooz	PWR: Pressurised Water Reactor	1
Brennilis	HWR: Heavy Water Reactor	1
Saint-Laurent-des-Eaux	GCR: Gas-cooled graphite-moderated reactor	2
Chinon	GCR: Gas-cooled graphite-moderated reactor	3
Bugey	GCR: Gas-cooled graphite-moderated reactor	1
Creys-Malville	FNR: Fast Neutron Reactor (fast breeder reactor)	1

FUEL CYCLE FACILITIES

Uranium ore which is extracted from the mine is crushed, ground and then impregnated with an oxidising acid solution to dissolve the uranium. The uranium is then selectively extracted from the solution and this is followed by several purification steps before obtaining a uranium mining concentrate called yellowcake. It is in this form that the ore arrives at the conversion plant.

WASTE FROM THE EXTRACTION **OF URANIUM ORE**

Uranium mining in France ended in 2001. The residues from ore treatment and some of the waste produced are permanently disposed of on the former mining sites (see Chapter 4).

Conversion

1

After purification of the uranium contained in the mined ore, it must 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 to the process used in the enrichment plants.

The transformation takes place in two steps:

In the AREVA plant at Malvési where the yellowcake is converted into uranium tetrafluoride;



Yellowcake

then in the AREVA plant at Pierrelatte, where a fluoridation process changes the uranium tetrafluoride into uranium hexafluoride.

The chemical process used in the AREVA plant at Malvési generates solid residue and liquid effluent.

This waste loaded with uranium-bearing solids until now has been managed in a lagoon system.

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

Pending a decision on the long-term method of managing waste produced by the AREVA plant at Malvési, this family is presented separately in the quantified reports of existing waste stocks at 31 December 2013 and in the forecasts.



Natural uranium consists mainly of two isotopes: uranium-238 and uranium-235. The fissile uranium-235 is much less abundant in the natural state than uranium-238: it only represents 0.7% of natural uranium.

Today, most reactors use uranium enriched to about 4% in uranium-235 as fuel.

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

The enrichment process used by AREVA's George Besse II plant on the Tricastin site since 2011 is that of centrifugation.

The UF₆ gas is introduced into a cylinder rotating at very high speed under vacuum, in a sealed housing.

The heavier molecules, under the effect of centrifugal force are sent to the periphery of the tube while the lighter ones (235U) migrate towards the centre.

The gas enriched in the light uranium-235 isotope, in the centre of the tube, rises. The gas enriched in heavier uranium-238 descends.

The enriched and depleted products are recovered at the two ends of the tube, at the top and bottom.

This elementary step of separation of the molecules is repeated in a set of centrifuges placed in series, called cascades.

The fuel conversion and enrichment facilities produce low-level or very low-level uranium-contaminated radioactive operating waste, which is disposed of at CSA and Cires. It is usually packed in drums or cement containers.

Manufacture of fuel rod assemblies

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

UOX (uranium oxide) fuel:

The enriched uranium hexafluoride is converted into uranium oxide powder then compacted into pellets to manufacture UOX fuel. The pellets are inserted into metal cladding to hold them in place, thus forming fuel assemblies.

The FBFC plant in Romans performs both these operations. Waste produced by the plant is essentially very-low-level waste from the operation and maintenance of facilities;



Uranium pellets (FBFC)

MOX fuel (mixed uranium oxide and plutonium oxide):

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

The plutonium used comes from the treatment of spent fuel at the AREVA NC plant at La Hague.

The waste produced by MELOX is technological LILW-SL and ILW-LL, one part of which is non-irradiating and contaminated by alphaemitting radionuclides.

The Cadarache fabrication complex (CFCa) located at the Cadarache CEA centre also produced MOX fuel 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. About 85% of the dismantling had been completed at the end of 2014.

The MELOX plant started industrial production in 1995. Its production licence is for 195 tHM of MOX fuel per year (heavy metal weight), intended for use in "light water" reactors in France and other countries.

4 Spent fuel processing

When removed from the reactor, UOX type spent fuel contains 95% uranium, approximately 1% plutonium and 4% final waste.

Spent fuel processing consists of reclaiming the recoverable materials, namely uranium and plutonium, and then conditioning the final waste.

The operations performed in the processing plants 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 assemblies into approximately 35 mm sections,
 - chemically dissolving the spent fuel contained in these sections using nitric acid,
 - separating the dissolved uranium and plutonium by chemical extraction and purification;

• treatment and conditioning of final 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 a glass matrix, poured into a stainless steel container (CSD-V); this waste makes up the majority of HLW,
- for PWR fuels, the metal components (cladding tubes, spacer grids, 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 ILW-LL,
- the cladding waste from the GCR series is currently stored in silos at La Hague or at Marcoule. The conditioning process is currently being studied.

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

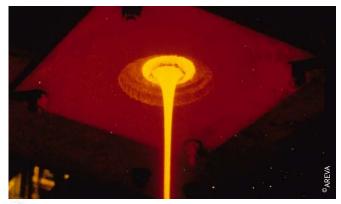
LILW-SL is disposed of at the CSA facility. It may first be treated at the Centraco plant by incineration or melting down, according to its physicochemical nature.

VLLW is conditioned in big bags or metal containers to be transferred and disposed of at the Cires facility.



Hulls from sectioned spent fuel





O Pouring vitrified waste into a CSD-V

OPERATIONS CONDUCTED IN PROCESSING PLANTS

UP1 plant at Marcoule

Spent fuel processing operations in the UP1 plant ceased at the end of 1997 and were quickly followed by the decommissioning programme, the largest decommissioning site in France. This continuity made it possible to leverage the expertise of the teams in place.

Over more than a decade, the equipment related to the plutonium extraction process gave rise to rinsing then decommissioning sites that have enabled the separation units representing the heart of this process to be fully decommissioned. In parallel with this, the first phase of level 1 decommissioning of the workshop dedicated to decladding was completed in 2013. This project will be completed before 2050 with the removal of the last waste, consistent with the availability of the deep geological repository which is scheduled to open in 2025. The decommissioning operations are aimed at:

- dismantling the production equipment;
- eliminating any radiological risk in all the buildings concerned;
- removing all the resulting waste.

These UP1 plant decommissioning operations, not including the support installations, involve one thousand rooms. They will produce approximately 27,000 tonnes of waste, most of which may be transferred to a surface disposal facility.

CEA acts as the contracting authority for the operations and is also responsible for the nuclear installations.

La Hague treatment plant

In 1966, a second spent fuel assembly processing plant was commissioned at the site of La Hague: UP2-400. It was operated by the CEA until 1976, and then by COGEMA (now AREVA). With a 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 fuel assemblies.

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

From 1987, UP2-400 was assigned in particular to the PWR series, while the UP1 plant at Marcoule processed fuel assemblies from the other series.

In the early 1980s, AREVA began building two new plants, which now process spent fuels, each of the same capacity (about 800 tonnes/year) to cater for French and foreign demand.

UP3 (started up in 1990) was initially dedicated exclusively to spent fuel supplied by foreign customers;

• UP2-800 was commissioned in August 1994 and seamlessly took over from the UP2-400 plant (decommissioned on 1 January 2004).

WASTE TREATMENT FACILITIES AND MAINTENANCE CENTRES

Running the various facilities that handle radioactivity entails related but required industrial support operations: treating the waste arising from facility operation and maintenance centres. The operator usually carries out this treatment and manages any waste produced.

In some cases, the operator may call upon dedicated off-site facilities to carry out these operations.

WASTE TREATMENT CENTRES

Socodei operates two processes in the Centraco facility at Marcoule:

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

It treats low-level incinerable solid waste and liquid waste produced by nuclear facilities, research laboratories and hospitals. The resulting ash and clinker is rendered inert and conditioned in packages sent to Andra's waste disposal facilities in Aube. The ingots produced by melting metal waste is either recycled for radiological protection incorporated in the waste packages, or sent to Andra's waste disposal facilities in Aube.

Following a smelter accident that occurred on 12 September 2011, the installation was shut down and restarting it was subject to prior licensing. Restarting the facility was licensed in April 2015. The incineration process, which was shut down at the same time as the smelter as a precaution, was restarted in July 2012.

STMI and Socatri in Bollène specialise in decontaminating radioactive material via conversion, conditioning and disposal operations. They thus produce radioactive waste.

Sogedec, in Pierrelatte, 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 areas of possible production of nuclear waste.

MAINTENANCE CENTRES

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

These maintenance centres generally hold more limited quantities of waste than the waste treatment centres, mostly intended for CSA.

The BCOT (Tricastin Operational Hot Point) in Bollène, carries out maintenance operations and disposal of contaminated equipment from EDF reactors.

Somanu, in Maubeuge, specialises in repairing, servicing and assessing equipment, primarily from reactor coolant and auxiliary systems.

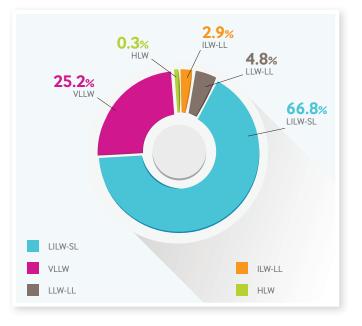
RADIOACTIVE WASTE STATEMENT AT THE END OF 2013

Category	Volume at the end of 2013 (m ³)*	
HLW	2,700	
ILW-LL	26,000	
LLW-LL	42,000	
LILW-SL	580,000	
VLLW	220,000	
Total	~ 880,000	

* Figures are rounded.

With regard to waste from AREVA's Malvési plant, for which the longterm management mode is being decided upon, the volumes are as follows:

Category	Volume at the end of 2013 (m ³)
uranium conversion treatment residues	690,000



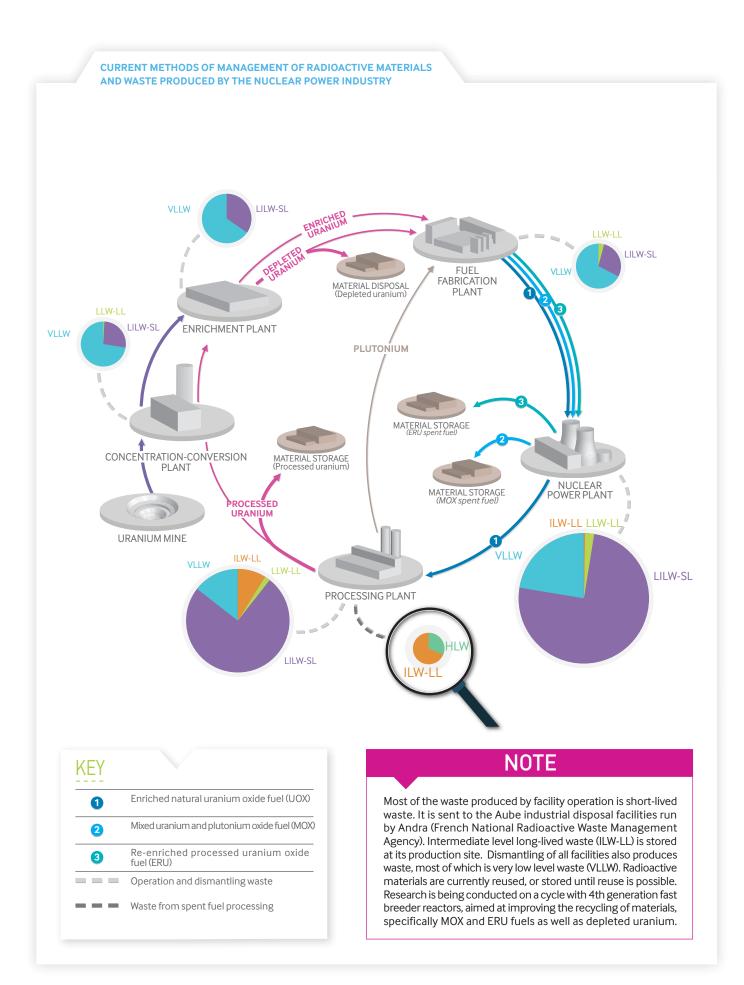
STOCK OF RADIOACTIVE MATERIALS AT THE END OF 2013

Radioactive materials	Mass (tHM)*
UOX fuel before use	440
UOX fuel in use in nuclear power plants	4,400
Spent UOX fuel, awaiting reprocessing	12,000
ERU fuel before use	-
ERU fuel in use in nuclear power plants	200
Spent ERU fuel, awaiting reprocessing	420
Mixed uranium-plutonium fuel before use	38
Mixed uranium-plutonium fuel in use in nuclear power plants	410
Spent mixed uranium-plutonium fuel, awaiting reprocessing	1,500
Non-irradiated mixed uranium-plutonium fuel scrap, awaiting reprocessing	230
Non-irradiated uranium fuel scrap, awaiting reprocessing	-
FNR spent fuel, awaiting reprocessing	110
Plutonium from spent fuel after reprocessing, in all its physicochemical forms	50
Mined natural uranium, in all its physicochemical forms	26,000
Enriched natural uranium, in all physicochemical forms	2,800
Enriched uranium from the reprocessing of spent fuel, in all its physicochemical forms	-
Uranium from the reprocessing of spent fuel, in all its physicochemical forms	27,000
Depleted uranium, in all physicochemical forms	290,000
Thorium, in the form of nitrates and hydroxides	4
Other materials (new Superphénix core)	72

* Figures are rounded.



The new Superphénix core is the mixed uranium- and plutonium-based fuel which was to have replaced the fuel used during the operation of the plant. Given the final shutdown of Superphénix, this fuel reload has never been used and therefore has not been irradiated.



3.2 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 industry and the medical sector are therefore included.

This sector includes the civil research facilities and institutions of CEA, the French Alternative Energies and Atomic Energy Commission, and all the public or private research facilities. Aside from the CEA, some facilities use radioactivity primarily as a tool for characterisation and do not carry out research in the nuclear field and nuclear power in particular.

CEA CIVILIAN RESEARCH CENTRES

The nuclear power division of the CEA provides ongoing support to the nuclear industry in France by seeking to optimise existing nuclear reactors and the fuel cycle. It develops technical solutions for the treatment and conditioning of radioactive waste.

In accordance with the act of 28 June 2006, the CEA is conducting research on a 4th generation reactor prototype (ASTRID reactor). The CEA also pursues 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 cleanup and dismantling of its own nuclear facilities. It also conducts programmes regarding the impact of nuclear power on health and the environment.

The CEA has five civil research centres.

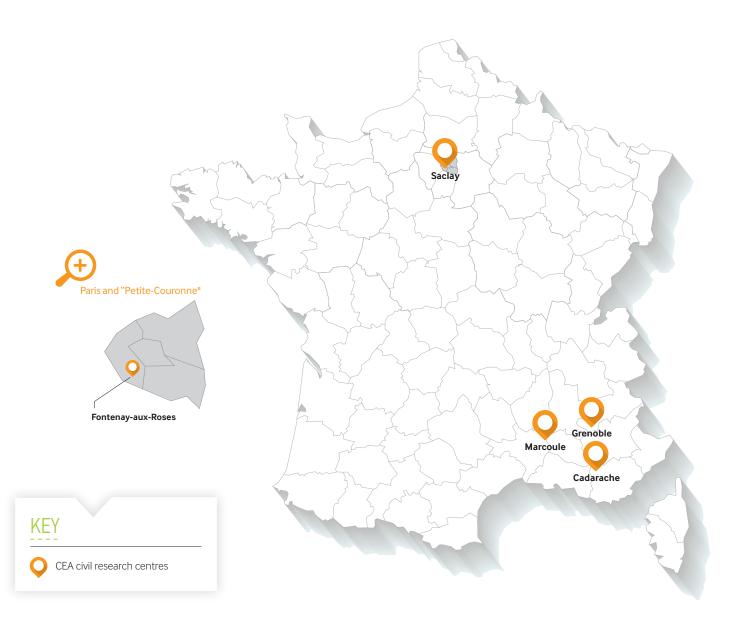
It runs many facilities, laboratories and nuclear research reactors as part of its R&D programmes. Management of these nuclear facilities produces waste similar to that of the other nuclear operators (maintenance operations waste, contaminated tools, etc.), although the waste is often more varied in nature. Its research activities on reactor operation and on spent fuel treatment generate the types of waste mentioned above.



Research laboratory



A The Phénix reactor hall at Marcoule



CEA's civil centres

CADARACHE

Activities at the Cadarache Centre are spread across several research and development (R&D) platforms mainly focusing on nuclear energy. For example, the ITER reactor has to be built at Cadarache. It will form a major leap forward from existing facilities to possible future electricity-generating reactors based on fusion, by demonstrating the scientific feasibility of this process.

Furthermore, the R&D activities carried out at Cadarache are aimed at optimising nuclear reactors and studying the behav-

iour of uranium- or plutonium-based fuels in different configurations.

The site has about twenty facilities including R&D facilities on nuclear fuel (experimental reactor of the FNR series now shut down: RAPSODIE, or the PWR series: SCARABÉE, CABRI) and irradiated materials, waste treatment facilities and installations for the disposal of waste and materials.

2 FONTENAY-AUX-ROSES ·····

The Fontenay-aux-Roses centre is undergoing major restructuring: its nuclear research facilities, which have been decommissioned, are the subject of a dismantling programme. Most of the waste produced is contaminated by alpha emitters and fission products.

Research areas at this site included chemical engineering, fuel assembly processing and the chemistry of transuranian elements.

GRENOBLE ·····

The denuclearisation programme of the CEA centre of Grenoble focuses on six nuclear facilities, the oldest dating from 1958: three research reactors (Mélusine, Siloette, Siloé), the Active Materials Analysis Laboratory (LAMA) and two effluent and nuclear waste treatment facilities (STED). The PASSAGE project was to dismantle and clean up these six facilities in 12 years. The three reactors were decommissioned in 2011, 2007 and 2015 respectively and demolished.

The work of cleaning up LAMA and STED is in the process of completion with a view to decommissioning these facilities no later than 2016.

MARCOULE

The Marcoule centre is involved in fuel processing activities. The waste from these operations related to R&D activities is included in the statements shown in the present section.

The installations operated at the Marcoule centre are dedicated to research and development of uranium preparation techniques, spent nuclear fuel processing, dismantling techniques for nuclear installations at the end of their life and management of the most radioactive waste.

The Phénix reactor built and operated by the CEA and EDF was a research tool especially for plutonium consumption and actinide incineration programmes. It was shut down in 2009 and is currently being dismantled.



Phénix plant at Marcoule

5 SACLAY ----

The Saclay centre boasts major facilities (LECI laboratory, ORPHÉE and OSIRIS reactors) 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 solids and INB 35 (STELLA) for liquid waste. Other waste is transferred to Marcoule or Cadarache for treatment and possible disposal. The pilot EL2 and EL3 reactors of the heavy water series are to be dismantled.



INB 35 - STELLA

BY THE ITER INSTALLATION

The nuclear waste generated by ITER will consist of technological waste such as the elements from replacing some components of the machine during its operation or dismantling waste.

The amount of radioactive waste generated during its operation is estimated at approximately 650 tonnes per year for 14 years. That generated by the dismantling of the installation at the end of its operations is estimated at approximately 37,000 tonnes. Over 90% will be very low or low level radioactive waste with low radiotoxicity managed through existing systems.

Low and intermediate level and long-lived waste (over 30 years) will be processed, conditioned and disposed of within the systems that will be implemented for this type of waste in accordance with the regulations. ITER will not produce any high-level waste.

It should be noted that for this industrial fusion reactor, research is currently planned for defining materials with low activation under irradiation (such as Eurofer), in order to significantly reduce the amount of waste produced. This is the objective of the IFMIF programme (International Fusion Materials Irradiation Facility). It is a research and development project using a materials irradiation facility to be built in Japan.

RESEARCH FACILITIES (EXCLUDING CEA CENTRES)

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

Many public and private facilities use radionuclides. Altogether, Andra has listed more than 400 producers in the research sector at the end of 2013 (excluding the CEA).

These include:

 medical research or Inserm laboratories, attached to medical or pharmacological faculties, and located in hospitals or university teaching hospitals;

 CNRS laboratories or mixed research units associated with the CNRS, usually located within faculties, institutes or Grandes Ecoles;

 units of the French National Institute of Nuclear Physics and Particle Physics (IN2P3), including the particle accelerators at Orsay and Caen (GANIL);

• the reactor of the Laue-Langevin Institute (ILL) in Grenoble and the European Centre for Nuclear Research (CERN), on the Franco-Swiss border;

- private sector firms such as Sanofi or L'Oréal;
- various decommissioned reactors and facilities.

In this sector, the most commonly used very short-lived radionuclides are phosphorus-32 and -33, sulphur-35, chromium-51 and iodine-125. In cellular and molecular biology, they are used

to mark the molecules in which they are incorporated. For short-lived radionuclides, tritium is often used.

With regard to the long-lived radionuclides carbon-14 is frequently used as a marker. These radionuclides are often used in the form of unsealed sources (i.e. small liquid samples). After use, they become liquid waste, which is generally collected by Andra to be forwarded to Centraco for treatment.



Centraco incineration facility

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

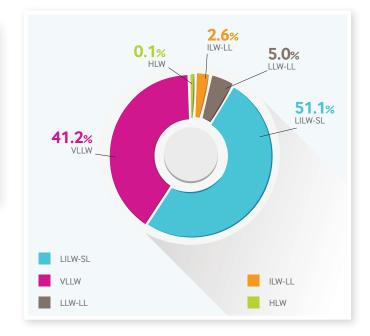
RADIOACTIVE WASTE STATEMENT AT THE END OF 2013

Category	Volume at the end of 2013 (m³)*
HLW	190
ILW-LL	10,000
LLW-LL	20,000
LILW-SL	200,000
VLLW	160,000
Total	~ 390,000

* Figures are rounded



At the end of 2013 CEA centres had produced almost 93% of the waste from the research sector.



STOCK OF RADIOACTIVE MATERIALS AT THE END OF 2013

Radioactive materials	Mass (tHM)*
Research reactor fuels before use	0.2
Fuel in use in research reactors	0.2
FNR spent fuel, awaiting reprocessing	43
Other civil spent fuel of the oxide type	57
Other civil spent metal fuels	19
Plutonium from spent fuel after reprocessing, in all its physicochemical forms	2
Mined natural uranium, in all its physicochemical forms	13
Enriched natural uranium, in all its physicochemical forms	14
Depleted uranium, in all its physicochemical forms	150

* Figures are rounded.

3.3 DEFENCE

This economic sector comprises the activities of the research, production and experimentation centres working for the nuclear deterrent force and the various armed forces (navy, air force, army, etc.), Defence Procurement Agency (DGA) and Gendarmerie.

RESEARCH, PRODUCTION AND EXPERIMENTATION CENTRES WORKING FOR THE NUCLEAR DETERRENT FORCE

This relates to 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.

1 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 on-board steam generators.



O The submarine *Redoutable* being dismantled

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The sites involved in the weapons and steam generator activities are classified as secret basic nuclear installations:

Bruyères-le-Châtel centre

Since it was set up, the 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.

Some limited specific activities relating to physics and analyses are continuing on the site.

Valduc centre

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

Its activities produce waste that is contaminated with alpha emitters and tritium. Valduc ILW-LL comprises various technological wastes conditioned in metal drums and sent to Cadarache.

Most of the sludge and concentrate packages locked in metal drums, previously produced by the effluent treatment station of the centre have been transferred for disposal at Cadarache.

LILW-SL consists of various metal and technological waste conditioned in 200-litre drums or in 5 m³ metal container boxes and effluent from the facility.

The VLLW produced is mainly operating waste.

The Valduc centre also produces tritiated waste, of which the most active and gas-discharging is conditioned in 200-litre drums and stored at the Valduc site.

Other centres

Explosive tests were carried out up to the end of 2013 at Moronvilliers. They used uranium depleted in isotope 235 The centre is now in a cleanup phase.

Similarly, explosive tests have been carried out in the past at the CESTA centre, some of which also used uranium depleted in isotope 235.



Mururoa Atoll

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

It is mainly VLLW waste that is found on these sites (metal waste,

various technological waste and waste from dismantling or cleanup) contaminated with uranium.

The Gramat centre is a centre of defence expertise regarding vulnerability and weapons efficiency in the face of conventional and nuclear weapon attacks. This test centre also used depleted uranium.

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

Finally, the CEA-DAM nuclear propulsion facilities at Cadarache operated by AREVA on behalf of the CEA are used to develop, qualify and provide maintenance for certain systems and equipment for nuclear steam generators for the French navy's nuclear-powered fleet.

2 Facilities that have stopped operating

Some facilities operated by AREVA on behalf of CEA-DAM were intended for the manufacture of components for nuclear warheads. This is the case of the Celestin reactors, the Tritium extraction facility at Marcoule (ATM) for which production was stopped in 2009 and 2011 respectively. Part of the waste from the cleanup/dismantling of these facilities is tritiated waste included under LILW-SL.

Since 2004, the CEA has acted as project owner for dismantling the UP1 plant which in particular extracts and purifies plutonium for military use before treatment of some 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 shown in the present section.

Since the production of fissile material based on highly enriched uranium for defence purposes has ceased, leading to the closure of enrichment and recycling plants, the CEA/DAM has acted as Project Owner for dismantling these plants at Pierrelatte.

It also ensures dismantling of the G2 and G3 GCR reactors at Marcoule which produced plutonium for the nuclear deterrent force.

Moreover, the CEA/DAM acts as Project Owner for dismantling the PAT and RNG reactors at Cadarache.

3 Pacific Test Centre

Waste from nuclear experiments carried out in the past is disposed of on the sites of Mururoa, Fangataufa and Hao in French Polynesia.

DISPOSAL OF TRITIATED WASTE

At the end of 2013, the volume of tritiated waste present in France is approximately 5,900 m³. Most of this waste (5,600 m³) is generated by activities related to the nuclear deterrent force.

In accordance with the recommendations for the disposal of tritiated waste drawn up by the CEA within the PNGMDR 2007-2009 framework, the CEA/DAM has built a first storage facility at Valduc to increase the capacity for holding tritiated waste from installations working for the nuclear deterrent force. This first building was commissioned in 2012.



Night vision goggles

DEFENCE FACILITIES

This activity sector covers professional activities relating to French defence (excluding the research, production and experimentation centres working for the nuclear deterrent force covered previously) holding radioactive waste, whether directly attached to the Ministry of Defence or working on their own behalf: the French armed forces (air force, army, navy), Defence Procurement Agency (DGA), Armed Forces Health Services (SSA) and Gendarmerie.

It should be noted that since 1 January 2009, the Gendarmerie is no longer attached to the Ministry of Defence but to the Ministry of the Interior. However, their waste typologies are the same as those of other staffs. In the remainder of this chapter, the Gendarmerie is therefore attached to French defence facilities.

Equipment 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.

When this equipment is worn out or becomes obsolete it constitutes waste and is listed in the inventory of each defence facility (around one hundred sites listed).

Some aircraft engine parts taken out of service and containing thorium are also listed (magnesium/thorium alloy housing, for example).

Several facilities have grouped this waste by category to centralise and streamline the way in which it is managed. This is the case, for example, of the site of Châteaudun for the air force. Since 2013 the site of Saint-Priest no longer accepts waste from the army and its final closure is planned for 2015.

Eventually, it is planned to have a single joint forces collection centre for radioactive waste: the Châteaudun site.

French defence harbours 2

The military harbours of Brest/Île Longue, Cherbourg and Toulon produce mostly VLLW waste, from construction activity, operation, maintenance and dismantling of nuclear submarine and aircraft carrier steam supply systems.

The reactor units of submarines being dismantled are stored at Cherbourg.

DCNS and DGA facilities 3

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

The DGA site at Bourges holds radioactive waste from experiments and testing conducted on weapons containing uranium depleted in isotope 235.

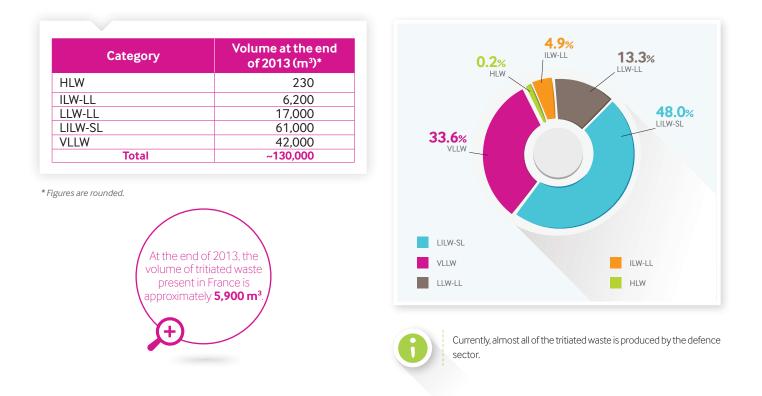


About a hundred sites producing and/or storing radioactive waste have been listed.

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

Most of these objects are considered as radioluminescent objects.

RADIOACTIVE WASTE STATEMENT AT THE END OF 2013



STOCK OF RADIOACTIVE MATERIALS AT THE END OF 2013

Radioactive materials	Mass (t)
Spent fuel for defence purposes	156

3.4 **INDUSTRY** OTHER THAN NUCLEAR POWER

INDUSTRY USING NATURALLY RADIOACTIVE MATERIALS FOR THEIR RADIOACTIVITY

This activity encompasses the manufacture and use of radioactive sources (sealed and unsealed) outside the medical field.

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

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. The sources are not automatically considered as final waste.

Furthermore, Article R. 4452-12 of the French Labour Code requires that sealed sources used be subject to regular technical radiological

protection inspections. Many sealed sources are returned to their suppliers abroad.

Pursuant to Article R. 1333-52 of the Code of Public Health, as amended by Decree 2015-231 of 27/02/2015, a sealed radioactive source is deemed to have expired not later than ten years after the date of the first registration on the supply form or, failing that, after the date it first came on the market, unless an extension is granted by the competent authority.

Others are stored in suitable premises. Some could be disposed of at the CSA provided they are compatible with the facility's safety requirements (see Report 4).

INDUSTRY USING NATURALLY RADIOACTIVE MATERIALS FOR PROPERTIES OTHER THAN THEIR RADIOACTIVITY

The radionuclides contained in some natural mineral raw materials are handled in activities related to the chemical, metallurgy and electricity production industries.

These activities may thus produce radioactive waste, which is mainly low- or very low-level waste.

Some industries only work with naturally-occurring radioactivity. Sometimes the nature of the materials used or the process employed tends to concentrate the radioactivity.

Therefore, the radioactivity levels of the waste produced may be 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.

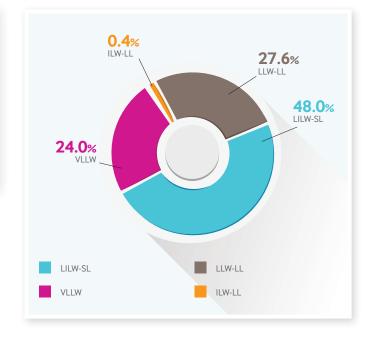
A typology of the industries currently likely to produce naturallyoccurring radioactive waste is described in Report 5.

The currently listed management solutions for this type of waste are Cires, the future LLW-LL disposal centre, the conventional disposal centres when the impact study has shown that there is no effect on human beings or the environment.

Some waste in the past was disposed of close to the installations.

RADIOACTIVE WASTE STATEMENT AT THE END OF 2013

Category	Volume at the end of 2013 (m ³)*
HLW	-
ILW-LL	170
LLW-LL	12,000
LILW-SL	22,000
VLLW	11,000
Total	~ 45,000



* Figures are rounded to two significant figures.

STOCK OF RADIOACTIVE MATERIALS AT THE END OF 2013

Radioactive materials	Mass (tHM)*
Mined natural uranium, in all its physicochemical forms	89
Thorium, in the form of nitrates and hydroxides	8,500
Suspended particulate matter (byproduct of the treatment of rare earth elements)	5

* Figures are rounded.

3.5 MEDICINE

This sector includes all public and private facilities that use radionuclides for medical analysis or treatment.

Medical research centres are not included as they form part of the research economic sector.

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This sector covers three major areas:

- biological analyses 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.

The facilities belonging to this sector mainly use unsealed sources, i.e. radionuclides in liquid solutions.

The main users of these radionuclides are nuclear medicine departments and their associated laboratories.

The same facilities also use sealed sources for radiotherapy, brachytherapy and calibration of instruments used to measure the activity of the products injected into patients (see Report 2).

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-life duration;

• treatment at Centraco and then disposal in Andra centres for longer half-life durations.

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

RADIOACTIVE WASTE STATEMENT AT THE END OF 2013

At the end of 2013, the volume of waste produced by these medical activities, excluding spent sealed sources, is of the order of 8,500 m³. Almost all this waste is in the LILW-SL category.

STOCK OF RADIOACTIVE MATERIALS AT THE END OF 2013

Radioactive materials	Mass (tHM)
Depleted uranium	15



Depleted uranium in the medical sector is used as radiation protection.



Tomography

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CHAPTER 4

LEGACY SITUATIONS

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Certain radioactive waste products were managed in accordance with the methods available at the time of their production and will not be handled in the Andra disposal facilities. This waste could be stored within or near their production sites, be used as backfill, handled within systems dedicated to the management of conventional waste or even disposed of at sea. These cases are referred to as "legacy situations".

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The modalities for the management of radioactive waste have evolved over time. This chapter lists the various sites containing radioactive waste resulting from management choices made at the time it was originally dealt with:

 removal of very low-level waste from conventional or nuclear industry to conventional waste disposal facilities;

 waste disposal inside or near nuclear facilities of basic nuclear installations or secret basic nuclear installations as well as in areas historically used as ancillary parts of these facilities;

• formation of dumps for waste with high natural radioactivity generated by the processing of raw materials containing naturallyoccurring radionuclides, but which are not used for their radioactive properties. They are not covered by the regulations on classified installations. This includes phosphogypsum waste from the production of fertilisers, residues from the production of alumina and residues from the activities of producing rare earths from monazite;

• disposal in the oceans (Atlantic or Pacific) of low- and intermediatelevel waste.

All of these sites (excluding those related to disposal at sea) are the subject of environmental monitoring, which checks that the impact of this waste is controlled, or if that is not the case suitable measures are taken to protect the environment and population.

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 since the corresponding waste will not be dealt with in Andra's operational or planned disposal facilities.

4.1 **CONVENTIONAL WASTE** DISPOSAL FACILITIES

In the past, conventional waste storage centres, now known as waste disposal facilities, were regularly or occasionally used to dispose of waste containing small quantities of radioactivity at levels of a few becquerels per gram. These practices are now prohibited for radioactive waste.

Very low-level waste that could have been stored in the past in conventional waste storage facilities consists essentially of sludge, soils, industrial waste, rubble and scrap metal from certain historical activities of conventional industry or civil or military nuclear industry, particularly dismantling and clean-up operations.

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This waste does not exhibit a radiation protection issue and could thus be eliminated via a conventional solution, in accordance with the regulations and instructions in force at the time. The disposal of radioactive waste in conventional waste disposal facilities is henceforth prohibited, since 1997 for non-hazardous waste disposal facilities, 1992 for hazardous waste disposal facilities, and 2004 for inert waste disposal facilities. Disposing of certain wastes with high natural radioactivity in such facilities may be authorised only under certain conditions.

There are thirteen conventional waste disposal facilities that have received radioactive waste regularly or occasionally listed in the National Inventory. They are located in the following places:

- Angervilliers in Essonne,
- Argences in Calvados,
- Bailleau-Armenonville in Eure-et-Loir,
- Bellegarde in Gard,
- Champteussé-sur-Baconne in Maine-et-Loire,
- Freney in Savoie,
- Menneville in Pas-de-Calais,
- Monteux in Vaucluse,
- Pontailler-sur-Saône in Côte-d'Or,
- Saint-Paul-lès-Romans in Drôme,
- Solérieux in Drôme,
- Vif in Isère,
- Villeparisis in Seine-et-Marne.

Among these facilities, four are now licensed to handle waste with high natural radioactivity, in accordance with the regulations in force (see Report 5). These are the hazardous waste disposal facilities of Villeparisis and Bellegarde and the non-hazardous waste disposal facilities of Champteussé-sur-Baconne and Argences.



KEY

Conventional waste disposal facilities that have received radioactive waste

4.2 LEGACY ON-SITE DISPOSAL SITES

In the past, some types of radioactive waste were disposed of near nuclear facilities or plants in accordance with the regulations of the time. They are mostly in the form of mounds or backfills. The sites identified in this chapter are those that the site operator or the waste producer has no plans to clean up the waste in the short term at the date of their declaration to the National Inventory.

At the end of 2013, the sites of this type listed in the National Inventory are the following:

The A126 motorway in Chilly-Mazarin:

Earth (1,700 m³) was used on the construction site of this motorway in the 1970s. This came from the cleanup of the former plant of Société Nouvelle du Radium (SNR) in Gif-sur-Yvette together with very low-level radioactive materials from clean-up operations of the former plant in Le Bouchet (2,200 m³). The average radium and uranium content of this earth is comparable to that found in nature (up to 3 becquerels per gram).

Montboucher mound:

This mound mainly contains waste that would be categorised today as VLLW (24,600 m³) produced during the cleanup of the former Le Bouchet plant between May 1975 and March 1977.

CEA centre Building 133 at Saclay:

Waste backfill that would today be categorised as VLLW ($17 \text{ m}^3 \text{ of}$ sandstone debris from old conduits and $57 \text{ m}^3 \text{ of}$ rubble and earth) were placed in the north and south foundations of Building 133 in the Saclay centre. Removal may be eventually conceivable as part of the deconstruction of Building 133 (not scheduled).

• The concrete basin of the former pilot decladding plant of the CEA centre at Marcoule:

This is an old STEL basin that was equipped for underwater decladding of fuel for a few months before the decladding workshop was made operational in 1959. This partially underground basin, containing some machinery and equipment used in the decladding process, was then filled with concrete. This basin with a total volume of 1,116 m³ is completely isolated from the process, all the piping having been removed. It has been sealed at the top. A quarterly inspection of surface contamination is carried out by the radiation protection department as part of periodic inspections. No anomaly has been detected to date.

The disposal area for inert waste of the CEA centre at Cadarache:

This waste disposal area was created when the centre was opened. 192,000 m³ of inert waste was stored there between 1961 and 2007, including 1,650 m³ of contaminated waste (4,600 MBq) stored between 1963 and 1991. The piezometer network was completed in 2002. This is used for monitoring the water table.

• The experimental wells of the PEM - Experimental Centre of Moronvilliers:

There are about a hundred wells containing residues from experiments that were conducted at the Experimental Centre of Moronvilliers. These wells have been filled in and sealed. As part of the inventory of polluted sites and soils, the CEA declared the PEM site in the BASOL database in May 1997. The entire site, including the hundred wells, is the subject of enhanced environmental monitoring the results of which are regularly sent by the ASND to the Prefect. Finally, radiometric mapping of the site conducted by helicopter confirmed control of the radiological reference frame of this site.

• The first six conventional waste disposal facilities of the CEA Valduc centre:

Until the early 1990s, due to the isolation of the centre, ordinary household and industrial waste and rubble were dumped in six locations on the centre, in accordance with the standards of the time and the practices all municipalities in France. These disposal facilities mainly involved ordinary, non-hazardous materials, deposited in hollows, such as valley heads. Waste and rubble were thus used to smooth out the areas in question. Radiological marking cannot be totally excluded due to former decontamination practices. Since the volumes concerned are large (an estimated 100,000 to 150,000 m³) and their level of radioactive contamination is estimated as zero or very low by the CEA, it does not plan any recovery. These disposal areas are, however, subject to monitoring, in particular by piezometers located downstream of the disposal areas, which ensures that no radioactive element capable of polluting groundwater can escape.

Area 045 disposal facility of the CEA Valduc centre:

This area has mainly received contaminated earth from the remediation operation in the "au tilleul" valley conducted in 1995. It consists of a silo, whose bottom and walls are lined with a membrane consisting of welded HDPE, sandwiched between two layers of geotextile fabric, the whole covered with sand. Containment is thus ensured. This earth has low activity (an average of 1 Bq/g and a maximum of less than 10 Bq/g). The volume concerned is 8,990 m³. This disposal area is monitored. Piezometers located downstream ensure in particular that no radioactive element capable of polluting groundwater can escape.

Mound at the Pierrelatte centre

This mound, with an area of approximately 37,000 m², was formed in the early 1960s. Between 1964 and 1977, trenches were made to dispose of 14,055 m³ of waste including fluorites from the treatment of uranium and chromate sludge. A groundwater quality monitoring plan has been in place since 1998 and the integrity of the structure is monitored.

Bugey mound

The presence of approximately 130 m³ of ion-exchange resins (nonradioactive according to the criteria of the time), buried between 1979 and 1984 at an artificial mound of about one million m³ of landfill was revealed in 2005 during the initial studies for siting the ICEDA facility south of the Bugey site. This mound consists of miscellaneous natural excavation materials and non-radioactive waste arising from the construction of the different production units. The quality of the groundwater in this area is monitored by eleven piezometers distributed around the mound.

Vernay lagoon in Loos-lez-Lille

This ore treatment site generated filtration sludge that was disposed of on the site (3,600 m³).

The site of the Chef-de-Baie plant in La Rochelle

35,000 m³ of solid residues from the treatment of monazite were used as landfill on the site of the plant.

The port of La Pallice in La Rochelle

The Solvay plant produced residues resulting from the treatment of very slightly radioactive natural materials. 50,000 m³ of these residues were used as landfill in this port.

It is estimated that between 250,000 and 300,000 m³ of waste has been disposed of on these sites. The upward trend in the inventory of this type of waste is due to the fact that the list of sites presented in the 2012 edition of the National Inventory has been supplemented by the sites arising from the investigations conducted as part of the National Radioactive Materials and Waste Management Plan.



The port of La Pallice in La Rochelle

Compared with the detailed list above, two additional situations were identified at the end of 2014 by the CEA as having to be reported in the inventory of legacy disposal sites:

- the internal disposal of Marcoule: with regard to this internal disposal, the investigations carried out do not indicate any radiological marking, however, the consistency between identified management practices implemented over time in the various centres would lead to the precaution of declaring this disposal to be of the same nature as those at Cadarache and Valduc. The current volume is estimated at approximately 126,000 m³ of waste consisting mainly of earth mixed with rubble. In order to characterise this volume, 32 uniformly distributed boreholes were drilled in the disposal down to the natural terrain encountered between 5 and 12 metres in depth;
- the trenches of the northern CDS zone of Marcoule: four trenches were successively operated from 1963 to 1993 in the northern CDS area to receive very low-level and low-level nuclear waste. This waste consists mainly of rubble, scrap metal, concrete, ash, sludge and earth from the site excavations, whose conditioning in drums was not justified at the time, and whose disposal in landfills was not acceptable. At the end of the operation of each of the trenches, clean backfill was put in place 1 m to 1.5 m above the waste. The four trenches contain approximately 50 000 m³ of waste.

These sites will be included in the National Inventory from the declaration at 31 December 2014.

MAP OF LEGACY DISPOSAL SITES IN FRANCE (DSH)



Legacy disposal facilities are monitored as part of the environmental monitoring programmes for the sites. Provisions for preserving the memory of the presence of waste (definition of specific easements taking into account the nature of the activity, its history and potential residual risks) have been made where appropriate.



4.3 **DISPOSAL FACILITIES FOR** WASTE WITH HIGH NATURAL RADIOACTIVITY

There are several dozen disposal facilities containing waste with high natural radioactivity in France. These include phosphogypsum waste deposits from the production of fertilisers, residues from the production of alumina and coal ash from thermal power plants, some still recoverable.

The main disposal sites for waste with high natural radioactivity are:

• disposal of phosphogypsum from the production of phosphoric acid used in the manufacture of fertiliser. These sites are no longer in use and are monitored:

- Anneville-Ambourville,
- Douvrin,
- · Rogerville,
- · Saint-Étienne-de-Rouvray,
- Wattrelos;
- disposal of residues from alumina production:
 - Gardanne,
 - Vitrolles,
 - · Marseille (Aygalades, La Barasse-Saint-Cyr, La Barasse-Montgrand);

- disposal of coal ash from thermal power plants and not recoverable:
 La Grand-Combe,
 - La Grand-Corrit
 Fuveau.
 - Tuveau,
 - Arjuzanx.

It should be noted that some of the coal ash slag heaps are recovered for use in building materials (concrete) (see Report 5).



4.4 **DEFENCE** DISPOSAL SITES IN POLYNESIA

Between 1966 and 1996, the French Government carried out nuclear experiments at the Pacific Test Centre, located 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 vertical shafts sunk into the rocks of the coral reefs (1975-1987) or under the lagoons (1981-1996).

The waste produced by this testing and the dismantling of the associated facilities was disposed of *in situ* in wells or dumped in French territorial waters.

The waste disposed of *in situ* as part of these operations is set out in the Geographical Inventory (Overseas).

When French nuclear testing in the Pacific finally ceased in 1996, France asked the IAEA to conduct a radiological assessment of the experimental sites of Mururoa and Fangataufa and the nearby areas. This assessment constitutes the baseline for activity levels in the environment of these two atolls.

Although the IAEA's experts had concluded that it was not necessary to continue radiological monitoring of the atolls of Mururoa and Hao, it was decided to maintain a monitoring programme in order to detect in particular any possible release of radionuclides from cavities and lagoon sediments.

This monitoring focuses on the environment of the two atolls and consists of two parts:

• continuous monitoring of atmospheric aerosols and the integrated dose;

an annual sampling campaign.

4.5 MINING SITES

Mining uranium in France between 1948 and 2001 (in open-cast or underground mines) led to the production of 76,000 tonnes of uranium. Exploration, extraction and processing involved approximately 250 sites of very varying sizes (from simple exploratory work to large-scale operating sites) spread over 25 departments in France. Ore processing has been mainly carried out in eight plants. All these sites are described in the National Inventory of uranium mining sites "MIMAUSA" (Memory and Impact of Uranium Mines): Synthesis and Archives) prepared by IRSN.

There are two categories of products from uranium mining:

 mine waste which means products consisting of soil and rocks excavated to access the deposits of interest. The volume of mine waste extracted can be estimated at 167 million tonnes;

 processing residues, meaning products remaining after extraction of the uranium contained in the ore by static or dynamic processing. The residues correspond, in fact, to process waste, whose volume can be estimated at 50 million tonnes.

Basically, the waste remained where it was produced. It was used in filling open-cast mines or underground mining structures such as shafts, for redevelopment by covering residue disposal sites or placed in a pile as spoil tips. Mine waste with a content of less than 100 ppm could be used as backfill, earthwork or as road foundations on places near mining sites. Their volume is estimated to be 1 to 2% of the volumes of waste extracted from the sites, or about two million tonnes.

The processing residues are disposed of on seventeen sites. This is VLLW and LLW-LL. There are two types of ore processing residues characterised by their specific activities:

• processing residues from low content ore (of the order of 300 to 600 ppm uranium) with a total average specific activity of 44 Bq/g (including about 4 Bq/g of radium-226). These residues, from static leaching (about 20 million tonnes) are disposed of either in tips, or in open-cast mines, or used as a first covering layer for dynamic leaching residue disposal sites;

• processing residues from high average content ore (of the order of 1,000 to 10,000 ppm uranium or 0.1 to 1% uranium) with a total average specific activity of 312 Bq/g (including about 29 Bq/g of radium-226). These residues from dynamic leaching (about 30 million tonnes) are disposed of either in former open-cast mines with sometimes an additional dyke, or in basins enclosed by an encircling dyke or behind a dyke damming a thalweg.

The seventeen disposal sites concerned are:

- Bauzot,
- Bellezane,
- Bessines-sur-Gartempe Brugeaud,
- Bessines-sur-Gartempe Lavaugrasse,
- Bertholène,
- Gueugnon,
- Jouac,
 - La Commanderie,
 - La Ribière,
 - Le Cellier,
 - L'Escarpière,
 - Les-Bois-Noirs-Limouzat,
 - Lodève,
 - Montmassacrot,
 - Rophin,
 - Saint-Pierre-du-Cantal,
 - Teufelsloch.

Very low-level waste linked to the use or dismantling of ore processing facilities or other front-end facilities in the cycle was also disposed of *in situ* at some of these sites. The sites concerned are Bauzot, Saint-Pierre-du-Cantal, Bessines-sur-Gartempe, Gueugnon, Lodève, Jouac, L'Escarpière and Les-Bois-Noirs-Limouzat.



O The uranium mine at Bellezane after rehabilitation



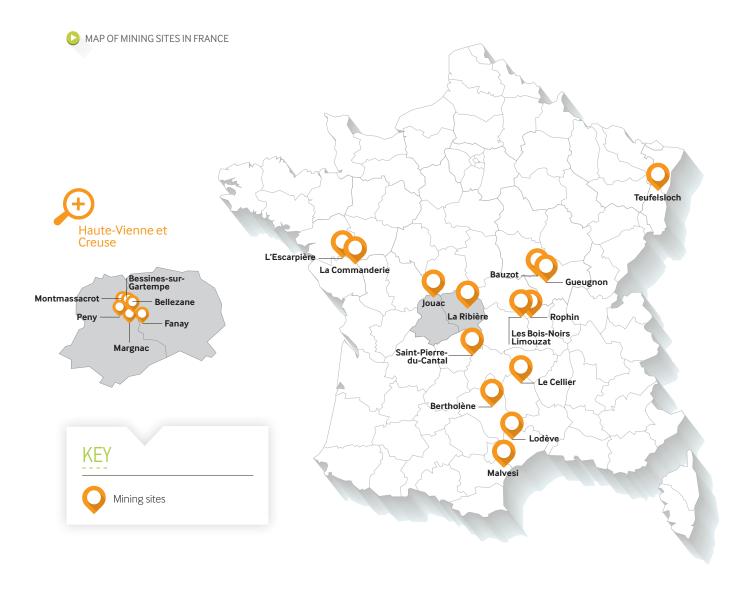
The MIMAUSA inventory may be consulted on the website of IRSN: http://mimaubdd.irsn.fr

Moreover, three sites managed as part of La Crouzille mining division (AREVA, formerly COGEMA) were used in the 1970s and 1980s as dumps for very low-level waste from various front-end facilities in the cycle: Fanay, Margnac and Peny.

All of these sites are listed in the Geographical Inventory.

Under the French National Radioactive Materials and Waste Management Plan, AREVA submitted studies on the assessment of the long-term impact on health and the environment of the disposal facilities for mine processing residues (physicochemical characterisation of residues, geomechanical strength of dykes and the long-term radiological impact of the disposal facilities) and former mining extraction sites (management of diffuse waste and water treatment, long-term impact of mining waste). Furthermore, in 2010, the interdisciplinary expert group for the Limousin submitted a report on the current and long-term impact of these mining operations. This report puts forward monitoring management options [II].

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



[11] "Recommendations for the management of former uranium mining sites in France. Covering sites in Limousin and elsewhere over the short to medium and long term", Final Report prepared by the interdisciplinary expert group on uranium mines in Limousin, September 2010.

[III] Circular of 22 July 2009 on the management of former uranium mines.

4.6 **SITES** CONTAMINATED BY RADIOACTIVITY

The French Interministerial Circular of 17 November 2008 [V] gives the following definition of polluted sites:

"A site of radioactive pollution is any site, either abandoned or in operation, where natural or artificial radioactive substances have been or are being handled or stored under conditions such that the site poses risks to 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 Environmental Code, i.e. any "substance that contains natural or artificial radionuclides whose activity or concentration justifies radiological protection monitoring".

Thus the mere presence of radioactivity at a site, whether it is of natural or artificial origin, does not mean 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 source of the pollution for each of these sites is set out as a reminder in the Geographical Inventory data sheets.

They are mainly sites where radium (or objects containing it) was extracted, stored or marketed in the first half of the twentieth century.

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 radioluminescence).



Apartment cleanup site

OPERATION RADIUM DIAGNOSIS

Radium was used in certain medical activities, in particular for the first cancer treatments. This radionuclide was also used in craft activities such as clock-making and watch-making (for its radioluminescent properties) and the manufacture of lightning rods or cosmetics until the 1960s.

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

These activities may have generated traces of pollution. On the basis of the various inventories of industrial sites that may have held and used radium and in particular that updated by the Institute for Radiological Protection and Nuclear Safety (IRSN) in 2007 at the request of the French Nuclear Safety Authority (ASN), some sites have now been identified by the state authorities as having housed an activity using radium in France. The radiological status of these sites is unknown or poorly known to the state authorities. The sites may include private housing or business premises. Estimated at 134 at the launch of Operation Radium Diagnosis in 2010, the number of sites requiring a diagnosis was revised to 164 after adding more recently identified addresses.

Operation Radium Diagnosis, managed by the French Nuclear Safety Authority (ASN), 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 and the health of the populations concerned is monitored.

Lastly, the sites showing radium contamination are rehabilitated by Andra.

This proactive and positive approach on the part of the public authorities is financed by public funds, whether it involves diagnosis, individual health monitoring or rehabilitation.

The initial diagnosis phase, concerning the Paris region, began at the end of September 2010. Since that date, 30 sites have been diagnosed, some of which, particularly buildings in Paris, housed many apartments, offices and shops. Altogether, there are over 300 properties that have been checked in this way. Twenty-three of them have been identified as polluted, and six have already been rehabilitated.

M Circular of 17 November 2008 regarding the handling of certain radioactive waste and sites of radioactive pollution. Andra General Interest Mission.

There are also former industrial sites on which naturally radioactive ores were processed to extract rare earth elements, which led to pollution of the site by residues with high natural radioactivity.

This is the case, for example, of the former Orflam-Plast plant in Pargny-sur-Saulx (Marne), which made cigarette 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.



Orflam-Plast site

-- POLICY ON MANAGEMENT OF SITES AND SOILS POLLUTED BY RADIOACTIVITY --

Management of sites and soils 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 Act of 30 July 2003 and in the texts issued on 8 February 2007 by the ministry responsible for the environment. The specific case of management of sites and soils polluted by radioactivity is set out in the Circular of 17 November 2008, and also in the December 2011 ASN-DGPR-IRSN guide to management of sites and soils that could be polluted by radioactive substances [VI].

In practice, if exposure is found, it is advisable seek the actions to reduce such exposure that are suitable for, and proportionate to, the situation encountered.

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.

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, soils) 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 may 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 removal". It includes a study of the documents concerned and field investigations, and its primary aim is to confirm or refute the presence of the suspected pollution, and then, where applicable, to determine the location, nature 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 assessments of radiological exposure, based on scenarios of use by the general public or 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 for assessing, in concert with the stakeholders the relevance of the assumptions adopted and checking that the optimisation process has been carried out correctly. It must lead to a consensual long-term management solution.

[VI] ASN-DGPR-IRSN Guide to the management of sites and soils that could be polluted by radioactive substances of December 2011.

BASIAS DATABASE

France was one of the first European countries to systematically conduct inventories of sites likely to be polluted (excluding radiological pollution) (first inventory in 1978). The main objectives of the inventories are:

 listing, on a wide-ranging and systematic basis, all the industrial sites whether abandoned or not, that might cause pollution of the environment;

keeping a record of these sites;

 providing useful information for those active in urban planning, property development and protection of the environment.

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

http://basias.brgm.fr/

These sites may be classified into three categories:

• **remediated sites:** sites that have been remediated since the previous edition; those that were shown as being remediated in the 2012 edition are no longer covered by data sheets.

However, the record of these sites is held in the BASIAS database developed by the BRGM (http://basias.brgm.fr);

 sites undergoing remediation: the remediation work on these sites is in progress. They are mostly listed in the BASOL database (http://basol.developpement-durable.gouv.fr/);

• sites awaiting remediation: these sites have been found to show pollution and are awaiting remediation. Some of these sites are listed in the BASIAS database.

The Geographical Inventory at 31 December 2013 lists more than seventy sites:

- 17 sites remediated since the previous edition;
- 23 sites undergoing remediation;
- 31 sites awaiting remediation.

In the table below, by convention, one site corresponds to one owner. The number of sites per locality is shown in brackets, depending on the site's status.

BASOL DATABASE

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

http://basol.developpement-durable.gouv.fr/

NAVARRA CLEANUP SITE



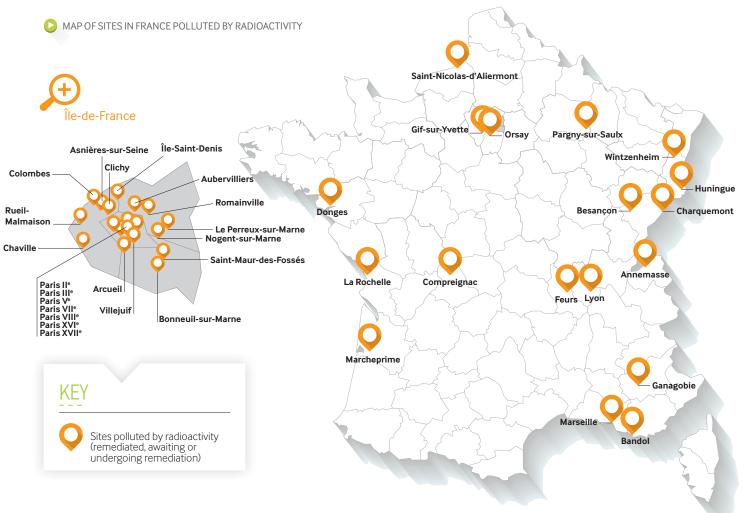
Navarra worksite

Navarra SARL (an industrial structure demolition company), based in Aquitaine in the municipality of Marcheprime, has recovered various materials and products in the course of its activity. These were stored on a plot of land on the site.

Following the termination of this industrial activity in 2008, a diagnosis of the site revealed radioactive contamination, generating the equivalent of about **400** m^3 of **VLLW waste**.

The operator has completed the decontamination of this industrial site. All the waste was handled by Cires in August and September 2014.

Remediated sites	Sites undergoing remediation	Sites awaiting remediation
Annemasse [2 sites]	Annemasse [1 site]	Aubervilliers [1 site]
Bonneuil-sur-Marne [1 site]	Arcueil [1 site]	Bandol [2 sites]
Compreignac [1 site]	Asnières [1 site]	Besançon [1 site]
Donges [1 site]	Chaville [3 sites]	Charquemont [1 site]
Gif-sur-Yvette [2 sites]	Feurs [1 site]	Chaville [3 sites]
Marcheprime [1 site]	Ganagobie [1 site]	Clichy [1 site]
Orsay [1 site]	Gif-sur-Yvette [2 sites]	Colombes [2 sites]
Pargny-sur-Saulx [3 sites]	La Rochelle [1 site]	Gif-sur-Yvette [3 sites]
Paris 2 [1 site]	Le Perreux-sur-Marne [1 site]	Huningue [1 site]
Paris 3 [1 site]	Lyon [1 site]	Île-Saint-Denis [6 sites]
Paris 5 [2 sites]	Marseille [1 site]	Marseille [1 site]
Rueil-Malmaison [1 site]	Pargny-sur-Saulx [2 sites]	Nogent-sur-Marne [2 sites]
	Paris 3 [3 sites]	Pargny-sur-Saulx [1 site]
	Paris 17 [1 site]	Paris 7 [2 sites]
	Saint-Maur-des-Fossés [1 site]	Paris 8 [1 site]
	Saint-Nicolas-d'Aliermont [1 site]	Paris 16 [1 site]
	Wintzenheim [1 site]	Romainville [1 site]
		Villejuif [1 site]
17 sites	23 sites	31 sites



4.7 WASTE DUMPED AT SEA

Disposal at sea has always been a means of managing all types of waste. Radioactive waste has been no exception. The simple solution of dumping this waste at sea was in fact considered safe by the scientific community since the dilution and assumed duration of isolation provided by the marine environment were sufficient. This practice was therefore implemented by many countries for more than four decades, starting from 1946.

First organised by the waste producers themselves, dumping at sea was coordinated by international bodies from the 1960s. It is within this framework that France proceeded to the disposal of radioactive waste in the Atlantic, taking part in campaigns organised by the NEA in 1967 and 1969. During these two operations, France thus disposed of 14,200 tonnes of conditioned radioactive waste at sea, with a total activity of about 350 TBq, all from the Marcoule site.

Upon the commissioning of the Channel disposal centre in 1969, France relinquished sea disposal for the management of most radioactive waste.

This method of management, however, continued to be used by France, up to 1982, for waste generated by activities related to the nuclear tests in French Polynesia: 3,200 tonnes of radioactive waste, with a total activity of less than 0.1 TBq, were so disposed of in French territorial waters in Polynesia.

It should be noted that there has been no French disposal of radioactive waste in the Channel: only the United Kingdom and Belgium have used the Casquets trench to the north-west of Cap de La Hague.



Radioactive waste being dumped into the sea in the 1960s.





CHAPTER 5

SPECIAL REPORTS

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[©]Andra/M. Saint-Louis

REPORT 1

EXISTING AND PLANNED SOLUTIONS IN FRANCE FOR LONG-TERM MANAGEMENT OF RADIOACTIVE WASTE

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INTRODUCTION

Like many other countries, France has chosen to set up a long-term solution for managing radioactive waste. This solution is based on definitive disposal, which isolates waste the time needed for its radioactive components to decay to a level that no longer presents a risk to humans or the environment.

Each disposal facility is designed for a specific type of waste and integrates multi-barrier confinement, generally consisting of the package, the disposal facility and the site geology, in order to ensure safety.

There are currently three French surface disposal facilities (two in operation and one in the monitoring phase) that handle more than 90% of the radioactive waste (VLLW and LILW-SL) produced each year in France. For the other types of waste (LLW-LL, ILW-LL and HLW), suitable repositories are currently being developed. In the mean time, the waste is stored in specific facilities, generally at the production site.



1. HLW AND ILW-LL

After 15 years of research on HLW and ILW-LL management and after a public debate, Planning Act 2006-739 of 28 June 2006, now codified in the French Environmental Code, established deep geological disposal as the only safe long-term solution to manage waste that, for safety or radiation protection reasons, cannot be disposed of in surface or near-surface facilities; this management is aimed at reducing the burden on future generations. For the implementation of this solution, the Planning Act tasked Andra with conducting studies and research to choose the site and design a deep reversible disposal facility for HLW and ILW-LL.

Andra is thus managing the geological disposal facility project Cigeo, for disposing of all HLW and ILW-LL produced at all current nuclear facilities, including waste from facility dismantling and reprocessing of spent fuels used in nuclear power plants.

If approved, Cigeo will be built along the boundaries of the Meuse and Haute-Marne departments in northeastern France.

Cigeo will consist of surface facilities that, amongst other things, will be used to receive and prepare waste packages as well as excavate and build the necessary underground structures. The waste will be buried some 500 metres below ground in an impermeable argillaceous rock formation able to contain radioactivity over very long periods.

Cigeo will be operated for at least 100 years, with enough flexibility for future generations to adapt the facility as needed.

Provided the necessary licences are obtained, the provisional calendar for Cigeo is as follows:

 2015, Andra will submit a proposal for an operational master plan to the French government, and a safety options package and a retrievability technical options package to the French Nuclear Safety Authority (ASN), with a view to the examination of the Cigeo construction licence application;

- 2017, submittal of a construction licence application by Andra;
- 2020, construction of the repository will begin;
- 2025, facility commissioning with a pilot industrial phase.

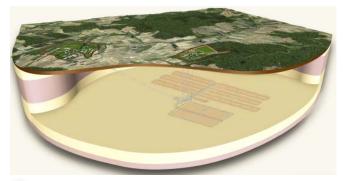


Diagram of surface and underground facilities for the Cigeo project

Pending Cigeo's commissioning, storage on the waste production sites is indispensable for the management of HLW and ILW-LL.

BEFORE DISPOSAL: STORAGE

Before disposal, waste is generally stored in dedicated facilities.

These storage facilities optimise the management of waste flow to the final disposal solutions (existing or planned) and maintain the waste in safe conditions, pending waste recovery for conditioning or removal to a disposal repository. Unlike a disposal repository, a storage facility is by definition temporary.

Its main functions are:

- logistical storage, for managing flows to Andra facilities, such as waste bound for existing disposal facilities;
- storage of raw waste, especially old raw waste, pending conditioning before disposal;
- storage of conditioned waste packages, pending the construction of facilities for high-level waste and low- and intermediate-level long-lived waste.

Storage facilities can also be used to allow decay of short-lived radionuclides contained in waste, in view of waste removal to the CSA, for example; or they can allow high-level waste packages sufficient time to cool before deep disposal.

2. LLW-LL

Programme Act 2006-739 of 28 June 2006, now codified in the French Environmental Code, entrusts Andra with the task of developing disposal solutions for graphite waste (generated by the operation and dismantling of first-generation gas-cooled graphite-moderated reactors) and radium-bearing waste. The French government also asked Andra to examine the possibility of including other low-level long-lived waste (LLW-LL) in the facility's inventory.

A national campaign to find a disposal facility site for LLW-LL was launched in 2008 at the government's request. Andra contacted 3115 municipalities situated on lands whose geological characteristics appeared favourable for a near-surface facility and presented them with the project. In late 2008, Andra provided the government with a report analysing the geological, environmental and socio-economic aspects of the forty-odd municipalities that expressed an interest in the project. After consulting the French Nuclear Safety Authority (ASN), the National Assessment Board (CNE) and concerned elected officials, the government asked Andra in 2009 to conduct in-depth geological investigations in two municipalities. However, these two municipalities had rescinded their candidacy.

In response, the government decided to push back the target dates to allow time for consultation; it also asked Andra to explore other possible scenarios for managing this waste, notably the separate management of radium-bearing and graphite waste.

In addition, the government tasked the High Committee for Transparency and Information on Nuclear Safety (HCTISN) with compiling experience feedback on the site search. The HCTISN submitted its recommendations to the government in September 2011¹.

1 HCTISN – LLW-LL Workgroup – Report and recommendations (in French) (http://www.hctisn.fr/IMG/pdf/rapport_gtfavl_vf_cle025317.pdf)

In response to this report, the French Ministry of Ecology, Sustainable Development and Energy asked Andra to continue its work to locate a disposal site, contacting existing nuclear facility sites as well as focusing on areas where municipalities had submitted a candidacy in 2008, as recommended by the HCTISN.

The Soulaines-dans-l'Aube community of municipalities, where surface disposal facilities operated by Andra are already located, agreed in 2013 to geological investigations. As requested by local elected officials, a consultation took place prior to any work in the field. The geological investigations conducted in the Aube department in northeastern France between mid-2013 and mid-2015 were aimed at improving knowledge of the local geology, in order to determine whether the subsurface characteristics are suitable for a low-level long-lived waste disposal facility and for very low-level waste.

In compliance with the 2013-2015 PNGMDR, Andra will submit a status report on LLW-LL management in 2015. This report will cover: 1) the results of the geological investigations carried out within the Soulaines intercommunal authority; 2) the waste inventory selected for the subsequent studies and the initiatives to be taken for consolidating this inventory, for example the characterisation of long-lived radioactive elements; 3) the design options examined; 4) the preliminary evaluation of the repository's performance after closure; and 5) the project calendar with its different steps.

Pending Andra's construction of a suitable disposal facility, LLW-LL is most often stored on production sites or, particularly for industrial waste not from nuclear power generation, at Andra's waste collection, storage and disposal facility (Cires).

----- CIRES STORAGE FACILITY

In 2012 at Cires, Andra commissioned a long-lived radioactive waste storage building especially intended for industrial waste not from nuclear power production; the building has a surface area of $2,000 \text{ m}^2$.

This waste, mostly LLW-LL with some ILW-LL, is stored in different halls, depending on radiological characteristics. The waste will be progressively recovered for disposal as the disposal facilities are commissioned.

The main types of waste stored at Cires at the end of 2013 are:

- radioactive lightning rods;
- radioactive objects from private owners (radium fountains, radioluminescent objects, etc.);

 radioactive medical artefacts used between the two world wars (collector's items such as radium needles, tubes and compresses);

• waste (e.g. soil, rubble) resulting from cleanup of sites contaminated by radioactivity from long-lived radioactive elements (radium, thorium).



Geophone used in 2013 LLW-LL geological investigations



LLW-LL geological investigations in 2013

3. LILW-SL WASTE

Low- and intermediate-level short-lived waste (LILW-SL) has been disposed of at surface facilities in France since 1969. There are two French facilities for waste in this category: the CSM and CSA disposal facilities.

Around 527,000 m³ were in disposal at the CSM facility between 1969 and 1994. CSM has been in the monitoring phase since 1994 and therefore no longer accepts waste.

The CSA facility, in operation since 1992, is located in the municipalities of Soulaines-Dhuys, Epothémont and La Ville-aux-Bois in the northeast of France. It covers a surface area of 95 ha, including 30 ha for disposal, with an authorised capacity of one million cubic metres for radioactive waste packages.

Waste disposed of at CSA is conditioned in concrete or metal packages. These packages are disposed of in reinforced concrete structures 25 metres long and 8 metres high, built in a geological zone consisting of a clay layer overlain with a sandy layer. The clay layer is impermeable and acts as a natural barrier in case of accidental dispersal of radioactive elements in the subsoil. Above the clay, the sandy layer drains rainwater to a single outlet, which simplifies environmental monitoring. The space between the packages in a structure are filled with concrete or gravel, depending on whether the packages are metal or concrete. The structure is then sealed by a concrete slab and covered with an impermeable polyurethane layer. When the facility ceases operation, the structures will be buried under a primarily clay cap to contain the waste over the long term; then the site will be monitored for at least 300 years.

The impermeability of the structures is verified via a network of underground drifts inspected on a regular basis.



Disposal of an LILW-SL package

4. VLLW WASTE

As requested by public authorities, Andra has developed a specific solution for very low-level waste. In many countries, below a certain radioactivity level or "clearance level", waste is managed as conventional waste. In France, all waste containing or liable to contain radioactive elements is managed by dedicated disposal routes.

Since 2003, this waste has been disposed at the Cires waste collection, storage and disposal facility in the municipalities of Morvilliers and La Chaise. This facility, which is classified on environmental protection grounds, covers a surface area of 46 ha of which 28.5 ha are reserved for disposal. It is designed to accommodate 650,000 m³ of waste, mainly from the dismantling of nuclear facilities in France. Its design is based on the hazardous waste disposal facilities in the chemical industry.

Waste packages are inspected upon arrival and deposited in cells excavated in clay, the base of which is engineered to collect seepage water. They are isolated from the environment by:

- a synthetic membrane around the cells of waste, together with a leaktightness monitoring system;
- the layer of clay underneath and on the sides of the disposal cells.

During use, the cells are protected by tunnel-shaped removable covers and equipped with monitoring devices. Once filled, the cells are covered with a layer of clay associated with a system for inspection and leach solution collection.



VLLW disposal cell

5. SPECIFIC CASES

TRITIATED WASTE

Tritium is a short-lived radionuclide (half-life of around 13 years) which is difficult to confine and may easily migrate into the environment. Waste containing tritium ("tritiated" waste) is thus managed in a specific way: it is stored for a time long enough to allow decay of tritium activity in the packages, which are then sent, depending on their level of radioactivity and residual gas release rate, to a suitable disposal facility.

At the end of 2013, the volume of tritiated waste was around 5900 m³. This waste is usually in solid form, but low quantities of liquid and gas tritiated waste exist as well.

The large majority of tritiated waste (around 95%, or 5550 m³ at the end of 2013) comes from the national defence sector, and almost entirely from nuclear deterrence activities. Industry along with medical and pharmaceutical research laboratories have used tritium in the past and continue to do so today: at the end of 2013, the corresponding volume was 350 m³. Finally, the ITER facility will also generate tritiated waste starting in 2024 and will become its leading producer, in its operation phase and then, around 2060, in its dismantling phase.

Tritiated waste is currently stored on the production sites. In 2012, the CEA commissioned a storage facility in Valduc for its own very low-level tritiated waste. Similarly, the ITER project includes the construction of a storage facility for waste produced by its operation and dismantling. The first storage modules will be available in 2027.

There are also plans to use the ITER storage facility to store tritiated waste from research (except CEA), industries not involved in nuclear power generation, and medicine.

Pending the commissioning of this facility, in case of an emergency impacting the environment or human health, this waste could be temporarily stored on the Valduc site, after authorisation on a case-by-case basis by the competent safety authority (ASND, the French Nuclear Safety Authority for Defence-related Facilities and Activities).



ITER under construction

VERY SHORT-LIVED WASTE

The majority of very low-level short-lived waste comes from hospitals and contains radionuclides with a half-life under 100 days that have been used for diagnostic or therapeutic purposes.

The decay of this waste is managed at the production sites; it is stored for a period longer than ten times the longest half-life for the radionuclides it contains.

This allows the radioactivity to decrease by a factor of 1000, at which point the waste can be removed via conventional routes.



O Decay tank

REPORT 2

WASTE TREATMENT AND CONDITIONING

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Compaction	
Incineration	
Melting	
Evaporation	
Cementation	
Bituminisation	
Polymer resin embedding	
Vitrification	

3. Conditioning R&D 107





1. **OBJECTIVES OF** WASTE TREATMENT AND CONDITIONING

When produced, radioactive waste is in raw form as a gas, liquid or solid. For management purposes, the waste must be **conditioned**, which entails producing "waste packages" that can be handled safely and that guarantee non-dispersal of radionuclides. Depending on the physical-chemical nature of the waste, conditioning may be preceded by treatment that transforms the initial waste so that its characteristics are suitable for long-term management; this involves reducing volume as well as toxicity as much as possible.

Conditioning may be defined as all operations by which waste (previously treated in some cases) is placed in a container, to which an embedding material may or may not be added; the end result is a waste package.

The choice of treatment, matrix and container is mainly linked to the characteristics, especially the radiological characteristics, of the raw waste. The aim is also the best volume reduction possible. For example, very low-level waste is simply placed in big bags or in large containers, without an immobilising matrix, whereas the fission product solutions from spent fuel reprocessing are vitrified then placed in welded stainless steel containers.

The main matrices used in industry to condition liquid or powder waste are as follows:

Vitreous matrix, for example with fission product solutions;

Bitumen, for example for embedding sludges and evaporation concentrates resulting from the treatment of liquid effluents;

 Cement matrix, for sludges, evaporation concentrates, incineration ashes, etc.

The homogeneous matrix containing the radionuclides is then poured into a container to produce a waste package.

For solid waste, two processes are commonly used:

 waste (possibly compacted) is embedded in a cementitious material after being placed in a container; • compacted pucks are directly piled in a container without the addition of cement.

Other processes may be used in specific cases:

• coprecipitation sludges may be dried then compacted in the form of pellets. These pellets are then placed in stainless steel drums. Sand is added to the pellets to fill in the empty spaces;

• in a final step, glass beads may be used to fill in empty spaces in the case of conditioning high-level solid waste.

The resulting waste packages are heterogeneous.

The containers have various shapes (cylindrical or parallelepiped), to suit their content. Various materials are used for these containers. Currently, the most common materials are concrete, possibly fibrereinforced, and stainless steel.

A waste package is generally composed of a primary container that holds:

 waste that was initially in liquid, powder or sludge form, incorporated in an embedding material;

- embedded solid waste;
- solid waste, possibly compacted.

To be integrated into a storage or disposal facility, the waste package must comply with acceptance specifications defined for that facility. These specifications are established based on the characteristics of the facility in question and define the expected performance levels for the package, depending on the waste contained. For example, they may prohibit the presence of putrescible waste, or liquids, or limit the quantity of gas released by a waste package.

DEFINITIONS

The various documents of the National Inventory use the following definitions, pursuant to the Order of 9 October 2008, as amended by the Order of 4 April 2014 []:

- "Conditioned waste" is waste that:
 - is accepted without additional treatment in an operational disposal facility, or
 - is compliant with the disposal acceptance specifications for the operational disposal facility it is to be sent to, or
 - has no additional treatment planned by its producer before disposal; in the case where there is no operational disposal facility for this waste;

• "Preconditioned waste" is waste that is not in bulk form and for which additional treatment (decontamination, immobilisation, compaction, vitrification, melting, injection, incineration, etc.) is planned by its producer before disposal;

• "Non-conditioned waste" is waste that is in bulk form; it is usually found in tanks, pits or silos.

2. INDUSTRIAL PROCESSES OF TREATMENT AND CONDITIONING

Since the 1950s and the commissioning of the first nuclear reactors in France, several treatment and conditioning processes have been developed to manage the waste produced by the various nuclear facilities. The main processes commonly implemented by industry are described below.

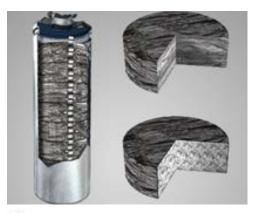
COMPACTION

Compaction aims to reduce the volume of certain types of solid waste, in particular metal or plastic waste. This process uses various press technologies with capacities ranging from a few hundred tonnes to a few thousand tonnes, depending on the type of waste to be compacted. After compaction, the waste is placed in containers and may be immobilised by cementitious material.

.....

Compaction is generally used by waste producers (such as La Hague and Cadarache), but the disposal facilities in operation also have compaction facilities.

For example, the Cires facility for the collection, storage and disposal facility of very low-level waste has two compactors.



 Standard package of compacted waste produced at La Hague

[1] Order of 4 April 2014, which amends the Order of 9 October 2008, on the type of information that managers in charge of nuclear activities and the companies identified under Article L.1333-10 of the French Public Health Code are obliged to collate, update and periodically send to Andra.

Similarly, the CSA disposal facility for low- and intermediate-level short-lived waste has a press for compacting low-mass scrap metal or waste such as rags and plastics preconditioned in 200-litre drums.

At the AREVA La Hague site, compaction is also used for conditioning structural waste from spent fuel after reprocessing, and for conditioning certain types of metal technological waste. Structural waste and technological waste are then placed in separate canisters. These canisters are then compacted. The resulting pucks are piled in a standard waste container in stainless steel; each package contains around eight of them.



CSA compactor

EXAMPLE

COMPACTED WASTE PACKAGES

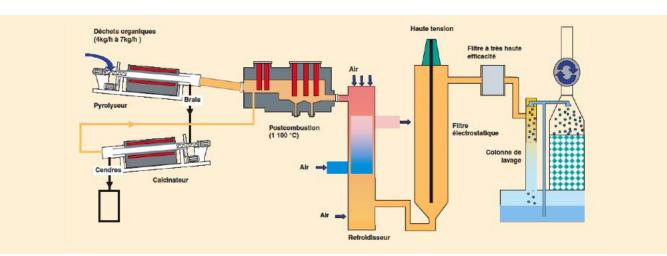
The structural elements of spent fuel assemblies for light water reactors (cladding tubes, end caps, spacer grids, springs) are compacted and conditioned in the hull compaction facility (ACC) at La Hague, commissioned in 2002. The packages also contain solid metal operating waste that has been compacted.

This waste package, in the F2-3-02 family, takes the form of a stainless steel container measuring around 1.4 metres high and 43 cm in diameter and containing around 600 kg of compacted waste.

INCINERATION

Incineration, which significantly reduces the mass and volume of waste as well as concentrating radioactivity in the ashes, is particularly well suited to aqueous and organic liquid waste or solvents, along with organic solid waste, especially VLLW or LILW-SL. The incineration residues take the form of clinker, slag and ash, which can then be conditioned by cementation.

Most of the time, incineration is carried out in Socodei's Centraco facility in Marcoule, in operation since 1999 and treating liquid and solid waste.



Basic diagram of the IRIS incineration process developed by the CEA

EXAMPLE



WASTE PACKAGE OF CEMENTED INCINERATED RESIDUES

In the Centraco plant, the incineration residues from aqueous and organic liquid waste, solvents and scintillation liquids, as well as incinerable solid waste from maintenance, take the form of clinker, slag and ash. These raw residues are crushed and mixed with a cement-based material; the resulting mixture is then poured into an unalloyed steel drum whose cover is welded to form a package of the F3-7-01 family.

The package mass is around 1.5 tonne for a volume of 450 litres; one package contains around 370 kg of raw incineration residues.

MELTING

Like incineration, melting reduces waste volume. It does not reduce mass, but it does decontaminate the waste to some degree, which may allow recycling. Melting is used for the treatment of metallic waste.

It is performed in the Centraco facility on steel or non-ferrous metal waste from maintenance or dismantling operations in nuclear facilities.

EVAPORATION

Before conditioning, liquid waste is sometimes concentrated by heating and evaporation, if its chemical characteristics allow for this; the result is reduced volume. The concentrates obtained are directly conditioned, by cementation or bituminisation, for example.

Evaporation is generally carried out on producers' sites, in the facility in which the concentrates are conditioned.

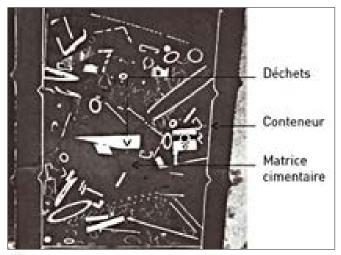
CEMENTATION

Cementation is used either to:

 condition solid waste such as technological waste, activated waste or structural waste. In this case, it results in heterogeneous waste packages; or • to embed waste in solution or in powder form: evaporation concentrates, chemical treatment sludge, ion exchange resins, etc. The resulting waste packages are homogeneous.

This is the most widely used conditioning process. Cement combines several favourable factors: availability, low cost, simplicity of use, good mechanical strength, and, in general, stability over time.

Although cementation is widely used on the sites of the waste producers (e.g. La Hague, Cadarache, Marcoule, Saclay), cementation facilities are also available at Cires and CSA.



 Cross-section of a bulk technological waste package immobilised by cementation

EXAMPLE



CEMENTED WASTE PACKAGES

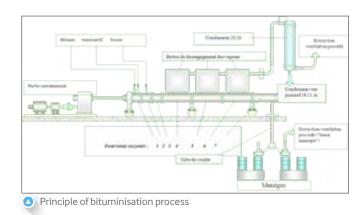
The waste generated by everyday operation of the various workshops and laboratories at the site of La Hague, and by maintenance and dismantling operations in its facilities, is conditioned in fibre-reinforced cylindrical containers. Based on the waste activity, these packages are either disposed of at CSA (F3-3-11 family) or stored pending the availability of a suitable disposal facility (F2-3-08 or F9-3-03 families).

The package mass is around 2.5 tonne for a volume of 1.18 m^3 ; one package contains around 450 kg of waste.

BITUMINISATION

The process of embedding in bitumen involves mixing the heated waste, in the form of sludge, with bitumen. The resulting mixture is dehydrated and poured into a container where it is cooled. Bitumen was originally chosen as an embedding material for radioactive waste for its high binding capacity, its chemical inertia, its impermeability, its low solubility in water, its high confinement capacity, its low cost and its availability.

This process is mainly used at the waste producers' sites for conditioning precipitation sludge that results from liquid effluent treatment. It is being progressively abandoned in favour of cementation or vitrification, depending on the types of waste to be treated.



EXAMPLE



BITUMINISED SLUDGE PACKAGES

Low- and intermediate-level effluents, produced by Marcoule facilities, are treated by chemical coprecipitation at the liquid effluent treatment station. The residual waste takes the form of sludge. This sludge is then embedded in a bituminous matrix and conditioned in stainless steel drums.

Based on the waste activity, these packages are either disposed of at CSA (F3-4-03 family) or stored pending availability of a suitable disposal facility (F2-4-03 family).

POLYMER RESIN EMBEDDING

Depending on their radiological and physical-chemical characteristics, solid waste can be embedded using a polymer resin, rather than cementitious material or bitumen. Among other applications, this process is used to condition the ion exchange resins used in the chemical and volume control systems for the reactor coolant systems

in nuclear reactors; these resins are also used for treatment and purification of pool waters as well as the treatment of spent effluents.

The process consists of mixing the ion exchange resins with an epoxy matrix, then conditioning them in cylindrical concrete containers.

i

VITRIFICATION

Vitrification consists of closely mixing, in a crucible heated to high temperatures, previously calcined radioactive waste (generally liquid) with glass frit whose composition is adjusted to the chemical nature of the waste; the aim is to homogeneously integrate, at the atomic scale, all the radionuclides present in the waste into the vitreous network. The resulting mixture is then poured into a stainless steel container. Due to its chemical composition and amorphous structure, glass is particularly resistant to heating and irradiation and offers good chemical durability over long time periods.

Used for several decades in the Marcoule and La Hague plants, this process has become the industry standard for conditioning fission product solutions produced by spent fuel reprocessing. Technological developments, for instance the use of a cold crucible, have made it possible to reduce the waste produced by the process and to widen the field of application to other types of waste.

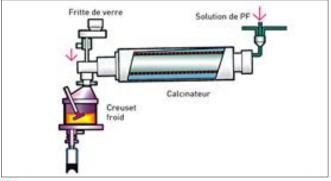


 Diagram of the cold crucible vitrification process in two steps (calcinationvitrification).

EXAMPLE

VITRIFIED WASTE PACKAGES

The first industrial use of vitrification took place in the vitrification facility at Marcoule in 1978. This facility, shut down since 2012, produced 3159 packages of vitrified waste (F1-4-01 family).

These waste packages take the form of a stainless steel container measuring around 1 metre high and 50 cm in diameter and containing around 360 kg of vitrified waste.

3. CONDITIONING R&D

PIVIC

TOWARD A NEW PROCESS FOR TREATING WASTE CONTAMINATED BY ALPHA EMITTERS

AREVA and the CEA, working together with Andra, are developing a new process for treating waste contaminated with alpha emitters. This project focuses on the treatment and conditioning of solid technological waste, a mix of metals and organic materials (vinyl, polyethylene, polymer gloves) that mostly come from the operation of the MELOX plant, where MOX is produced.

Much less radioactive than waste from spent fuel reprocessing, this waste must nonetheless be disposed of in suitable packages. This is where an innovative process known as PIVIC (in-can incineration vitrification) comes in. Its aim is to treat and condition the waste in a single step.

The principle is to introduce the waste in an oven and incinerate it using a plasma torch on a bath of molten glass. The resulting ashes are thus incorporated in the glass, and the waste container will contain a metal phase at the bottom and a glass phase at the top. This container will then be placed in a suitable package for disposal.

This process, currently being studied, brings together several processes, in particular plasma torch incineration, vitrification, melting using induction heating, and gas treatment.

If feasibility is demonstrated, industrial commissioning of the PIVIC process could take place around 2035.

GEOPOLYMER

DEVELOPMENT OF A SPECIFIC CEMENTITIOUS MATERIAL FOR MAGNESIUM WASTE

The magnesium waste stored in the pits of the Marcoule decladding facility takes the form of metal magnesium cladding in bulk, crushed or compacted. A specific cementitious material ("geopolymer") is currently being developed to control the physical-chemical interactions between the embedding material and the waste.

REPORT 3

DISMANTLING AND REMEDIATION

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1. DISMANTLING OF NUCLEAR FACILITIES

Like any industrial facility, a nuclear facility¹ has a limited period of operation. At the end of its service life, it must be dismantled so that the impact and residual risks for the public, the workers and the environment are as low as possible.

----- SECRET BASIC ------NUCLEAR FACILITIES

A secret basic nuclear installation is a geographical zone including at least one basic nuclear facility with defencerelated activities that requires special protection against nuclear proliferation, malicious acts or disclosure of classified information. All of the facilities and equipment, both nuclear and non-nuclear, within the above-mentioned zone are part of the secret basic nuclear installation. The nuclear installations included in the secret basic nuclear installation are called the "individual installations of the secret basic nuclear installation".

Nuclear safety and radiation protection of secret basic nuclear installations are ensured by the French Defence Nuclear Safety Authority (ASND), which is under the authority of the representative in charge of nuclear safety and radiation protection for defence-related activities and facilities (DSND). The ASND defines nuclear safety regulations for secret basic nuclear installations in a manner consistent and coordinated with the regulations defined by the French Nuclear Safety Authority (ASN). Both entities are independent of nuclear operators.

Phases in the life of a nuclear facility

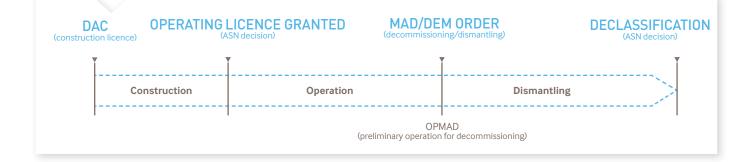
There are two major phases in the life of a nuclear installation:

- the operating phase;
- the dismantling phase, which follows decommissioning.

Except in cases of grave and imminent risk, the operator of a nuclear facility decides when to shut it down and informs the authorities of this decision. Once this decision is made, a preparatory phase for decommissioning begins. This transition step enables the operating teams at the facility, acting within the operating license, to begin removing as much radioactive and hazardous material from the facility as possible, to shut down process equipment, and to prepare for dismantling operations (site preparation, training of teams, etc.). In the case of a nuclear reactor, the fuel is removed from the facility. In the case of a reprocessing plant, for example, the process equipment is drained and rinsed. The required safety functions continue to be ensured.

At the end of the preparatory phase for decommissioning, the facility must enter the dismantling phase, which necessitates a new administrative order authorising decommissioning and dismantling.

At the end of dismantling, and under certain conditions, related in particular to the final condition, a nuclear facility may be declassified; in this case, it is no longer subjected to legal and administrative requirements.



LIFE PHASES OF A BASIC NUCLEAR INSTALLATION

1 In this report, the term "nuclear facility" refers to either a basic nuclear facility or an individual facility of a secret basic nuclear facility.

2 Dismantling strategy adopted in France

Two different strategies are possible for the dismantling of nuclear facilities:

 deferred dismantling, several decades after the facility is decommissioned, such that radioactive decay can occur and make the dismantling operations less complex;

• immediate dismantling, as soon as the facility is decommissioned.

The choice depends on national regulations, socioeconomic factors, funding capacity and method, availability of waste disposal routes, and availability of dismantling techniques and qualified personnel.

The strategy adopted in France is dismantling as soon as possible after facility decommissioning. This strategy makes it possible to use the knowledge and skills of the facility's operating teams, to avoid leaving the operations to future generations, and to ensure the availability of funds for carrying out the operations (see Section 1.5 of the 2013-2015 PNGMDR, "Cost and funding of waste management"). Implementing this strategy as quickly as possible depends on the availability of final disposal solutions.

DISMANTLING WASTE

The waste from dismantling operations is of two types: conventional and radioactive. To identify which category waste falls into, facilities are divided into zones based on the history of the facility and the operations conducted there:

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

• all waste from zones where radioactive waste may be produced (ZDN) is considered radioactive on principle, even if no radioactivity has been detected in it.

Waste zoning can be revised between operation and dismantling, to take into account specific characteristics of various phases and thereby optimise waste management. To declassify a ZDN zone to a conventional waste zone (ZDC), the structures of these zones undergo clean-up to eliminate the parts considered as nuclear waste.

1

Characteristics of waste from dismantling

Dismantling waste is 80% conventional waste, consisting of mainly of rubble and metal. The 20% that is radioactive waste is mostly very

DEFINITION: DISMANTLING

Dismantling refers to all technical operations which, after a nuclear facility has been decommissioned, are intended to eliminate radioactive and hazardous substances and the structures or equipment in which they were contained. These operations are carried out in order to reach a final state defined ahead of time, notably with regard to future use: disassembling equipment, cleaning rooms, soil cleanup or remediation, possible destruction of civil works, conditioning, and removal and elimination of the waste generated (both radioactive and non-radioactive).

DEFINITION: DECLASSIFICATION

Declassification is an administrative operation that removes the facility from the list of "basic nuclear facilities". The facility is then no longer subject to the legal and administrative requirements that apply to basic nuclear facilities. Declassification removes the obligation of regulatory inspections that a basic nuclear facility must undergo.

Declassification may be subordinated to the implementation of public service easements (use restrictions, monitoring, etc.).

low-level waste (VLLW) and low- and intermediate-level short-lived waste (LILW-SL):

materials from demolition work (concrete, rubble, scrap metal, glovebox walls, piping, etc.);

- process equipment (metal parts for example);
- tools and protective clothing (gloves, vinyl overalls, etc.);
- equipment rinsing effluents.

There may also be low-level long-lived waste, for instance graphite waste from the first French reactor system (graphite-moderated gas-cooled reactors) and intermediate-level long-lived waste in low quantities (activated waste, including metal parts from the reactor cores).

Radioactive waste from dismantling is managed in the same way as operating waste. It is sorted, undergoes treatment in some cases, and is then conditioned (see special report on treatment/conditioning), before being stored pending the creation of the suitable disposal route; or the waste is transported to the disposal facility that corresponds to its radioactivity level.

2 Estimated quantities of dismantling waste

During the preparation for dismantling operations, the quantity and type of waste to be produced are evaluated as accurately as possible and the treatment and conditioning methods are defined. The evaluations take into account all the waste resulting from the dismantling operation, including secondary waste; for example, the volumes of effluent generated by decontamination.

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.

The quantities of waste that will be produced by dismantling these facilities are evaluated using "technical ratios" regularly updated based on experience feedback from dismantling operations already completed. The ratios are used to calculate the quantity of waste resulting from the dismantling of each part of a facility, according to the nature and technical characteristics of that part and the radiological contamination measurements taken there.

DISMANTLING FROM AN INTERNATIONAL PERSPECTIVE

Worldwide, 300 to 400 nuclear reactors will reach the end of their lifetimes in the coming twenty years. Other nuclear facilities will also have to undergo clean-up and dismantling: dozens of research facilities along with fuel fabrication and reprocessing plants.

The biggest international markets are in North America, especially in the United States, but also in Europe. Significant growth is expected in Germany in a few years due to the decommissioning of eight of its nuclear power plants in 2011. There are also large-scale projects in the United Kingdom. Japan is a special case because of the Fukushima accident and the dismantling needs at that site.

Nuclear dismantling/cleanup operations are complex and require various types of expertise and specific technologies. Even though a majority of the operations use existing techniques, adjusted for the nuclear environment, the development of specific methods, processes and tools is necessary in certain fields. France has developed and been recognised for its expertise in radioactivity measurement, decontamination, robotics, cutting techniques (e.g. laser processes), as well as waste conditioning and treatment of the specific effluents generated by these operations.

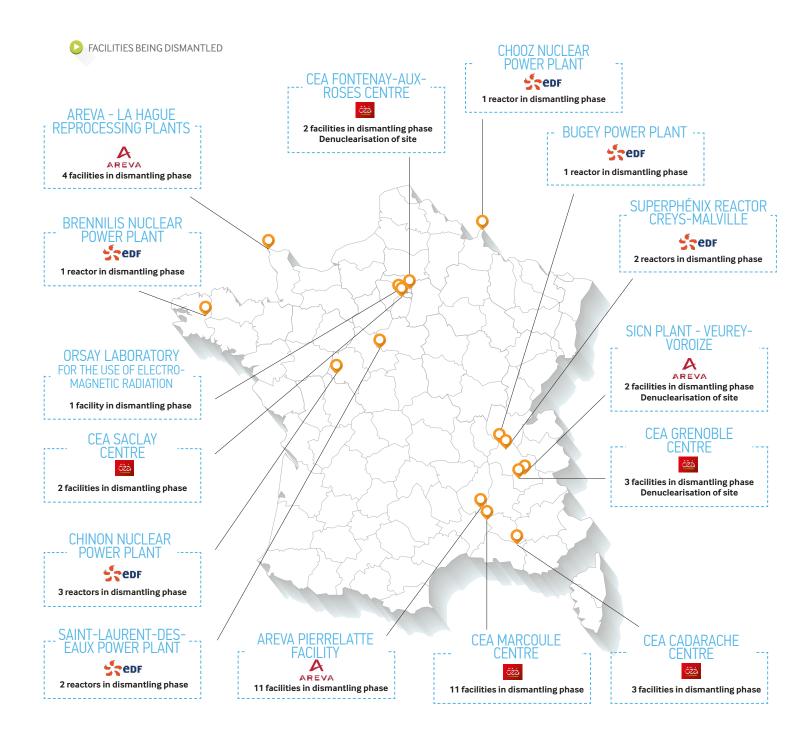
French companies have honed skills and knowledge in all the relevant fields, in an integrated fashion, through the dismantling/cleanup operations conducted in research or production facilities in the last 20 years; this clearly positions them to respond effectively to the challenges that these major international projects entail.

DISMANTLING OPERATIONS COMPLETED OR UNDERWAY IN FRANCE

For more than thirty years, dismantling operations in R&D facilities, research reactors, or fuel cycle facilities have been carried out at various sites. This has led to the declassification of 30 nuclear facilities, including 14 research reactors and two accelerators.

At the present time, nine first-generation nuclear reactors, with various technologies and designs (sodium-cooled fast reactors,

heavy water reactors, graphite-moderated gas-cooled reactors, etc.), are being dismantled by EDF. Other nuclear facilities are also being dismantled, for example certain AREVA facilities (fuel cycle) or CEA facilities (research reactors or prototypes, research facilities and laboratories).



Dismantling of two old sites: natural uranium fuel production and uranium metal machining

History of SICN industrial activities

SICN, a nuclear fuel company, was founded in 1957. It was headquartered from the start in Annecy in the facility already built for SACM, a mechanical construction company that produced equipment for the French navy. As early as 1954-1955, a facility was set up in Annecy to manufacture fuel elements for the G1, G2 and G3 reactors, in coordination with the CEA Saclay Centre. As the CEA wanted SICN to get a rapid start on the studies and development of the future fuel elements for the graphite-moderated gas-cooled reactors, a project to build the Veurey SICN Laboratory was soon under way. The laboratory began its activities in November 1960.

From 1961 to 1980, metallurgical and material behaviour studies along with design and manufacturing studies for uranium metal and sintered UO_2 fuels were conducted for research reactors, graphite-moderated gas-cooled reactors and fast neutron reactors in two basic nuclear installations: 65 (nuclear fuel fabrication plant) and 90 (pellet fabrication facility), both on the Veurey site.

After 1980, the activities were oriented toward uranium metal machining (CEA/DAM), the development of processes for test reactor fuels (e.g. MOX) and the fabrication of special machines.

For the Annecy site, whose activities were regulated by legislation concerning facilities classified for environmental protection, until 1980 it mainly focused on the development and fabrication of fuels for graphite-moderated gas-cooled reactors, using uranium metal. Its activities were then diversified to include general mechanics and micromechanics. During this same period, in 1980, SICN joined the COGEMA group, today AREVA NC. Fabrication of fuel for graphitemoderated gas-cooled reactors in the main building was discontinued in 1992. SICN then turned toward the manufacture of long-rod penetrators in depleted uranium (activity abandoned in 1998) and the production of various steel components for industry.

In 2002, a decision was made to stop all activities and initiate the dismantling and cleanup project.

In 2013, the end of the dismantling and development work made industrial use of the two sites possible once again.



Project objective and challenges

In 2003, the objective of the SICN project (Veurey and Annecy) was to clean up the two sites and to proceed with the dismantling necessary for their declassification and later industrial use.

The main challenges involved the treatment of around 100,000 m² of developed surface area in the buildings, the removal of pipework and sumps, and the removal of more than 16,000 tonnes of VLLW produced by the cleanup work; the operations between 2003 and 2012 were conducted in view of attaining the final state defined with the French Nuclear Safety Authority (ASN) and the Haute-Savoie Regional Directorate for the Environment, Land-Use Planning and Housing (DREAL).

The targeted final state reduces the impact and residual risk of the facilities with regard to the public, the workers and the environment to the lowest level possible.



Veurey site

PHASES OF THE DISMANTLING PROJECT



Waste reconditioning site



Veurey work zone

The dismantling project was carried out in three phases:

"Preparation for dismantling"

This first phase ran from the end of industrial activities in 2002 until the orders authorising decommissioning and dismantling were obtained in 2006 for Veurey and the prefectoral orders for work completion were obtained in 2005 for Annecy.

During this period, the preparatory operations for decommissioning (OPMAD) were very intense and involved removing residual radioactive materials and returning them to their various owners (around 70 tonnes) as well as preparing maps and performing radiological and chemical investigations of the sites' different zones to define the categories of surfaces to be treated in the buildings and the associated operating procedures; impact studies for the outside areas were also performed.

Logistically, the main focus was on preparing the future sites and especially, organising the management of waste removal from the production zones to the disposal facilities, including the acceptance documentation.

The most significant work involved preparing a waste storage hall, replacing the effluent treatment station, installing changing rooms, rerouting utility networks, and moving materials and equipment.

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PHASES OF THE DISMANTLING PROJECT



Disassembly of machine-tools and gloveboxes



Cleanup of floor slab and galleries of building A



 Deconstruction work under a vinyl tent in the old Annecy foundry

"Dismantling work"

The second step of the project entailed dismantling work performed between 2005 and 2012. The operations were carried out building by building until all the "nuclear" waste zones had been declassified. The civil structures in the buildings on the sites were cleaned up according to ASN recommendations [I] and the result was approved by the competent administrations. This procedure of civil structure cleanup was applied to each building based on its history and the initial radiological maps, which gave an accurate view of the surfaces to be cleaned up.

The production equipment and utilities (machine-tools, glove boxes, ventilation systems, process pipework, electrical supply, industrial water and compressed air systems) were removed and conditioned prior to cleanup and dismantling of the structures in each building.

Cleanup and dismantling of the building structures made it possible to deal with the civil structures, structural steelwork, and underground galleries and pits. Several scenarios were studied based on the buildings' specific characteristics, in particular the nature of materials and their type of contamination, to define confinement methods (possibility of vinyl tents) and tools.

During this period, the waste produced was mainly taken to Cires (around 16,000 tonnes of VLLW for the two sites, requiring 1,000 transport operations). A portion of the waste referred to as "exotic waste" was also dealt with before incineration at Centraco; this operating waste included contaminated oils and sludge from the effluent treatment stations.

PHASES OF THE DISMANTLING PROJECT

"Re-industrialisation of sites"

The third phase involved operations to re-industrialise the sites (2011/2013). It included all the demolition and development work aimed at making the surface area reusable. All above-ground building structures that remained were deconstructed using conventional methods. The volumes between the underground civil structures, such as technical galleries, were filled in using conventional materials. As for the pipework and sumps, all systems used for uranium-bearing water were removed. Finally, certain areas were tarred over to enable traffic on the sites in the future.

Also during this period, the applications for public service easements for each site and the application for declassification of the Veury nuclear facility were prepared.

3 Current situation of the sites

At present, for the Annecy site, the prefectoral orders for public service easement and monitoring were issued on 1 July 2014. The site's entire surface area has been rented and is being reused. Re-industrialisation will be completed by the industrial commissioning of the gas and wood boilers by the company IDEX.

For the Veurey site, the public service easement and declassification applications filed in March 2014 are currently being examined by ASN. As to the reuse of the site, 60% of the surface area and all of the site's utilities have been rented to SOFRADIR, a company specialised in infrared technology. Reuse of the remaining plot is under study with METRO (Grenoble metropolitan area).

4 Conclusion

AREVA coordinated all the dismantling and cleanup operations at the SICN Veurey and Annecy sites. The work performed included aspects of regulatory monitoring, which enabled SICN/AREVA to establish the following lessons learned for this project:

 initial objectives reached, in economic conditions adjusted to the context (regulatory changes);

• importance of an accurate definition of the final state to enable accurately evaluating the means necessary for attaining the objectives;

 importance of defining waste zones and characterising the radiological state; cleanup management methods depend on this prior step.

These findings were based a large range of room and structure types and of contamination modes, making it possible to apply this experience feedback to other dismantling and cleanup activities.



Annecy site



Veurey site

Passage, a successful denuclearisation project at the CEA Grenoble Centre

1 CEA Grenoble Centre

Created by Louis Néel in 1956 to promote the development of the French nuclear power industry, the CEA Grenoble Centre began to focus less on nuclear research at the end of the 1990s, turning to the development of innovative technologies in three main sectors: energy, information and healthcare. Starting in 2001, the Centre conducted an ambitious project of dismantling and cleanup in 6 nuclear facilities (Passage project), giving priority to safety, respecting the environment, managing skills, and communication with a broad segment of the public.

The six nuclear facilities - three nuclear reactors, an analysis laboratory for radioactive materials and two facilities for nuclear effluent and waste treatment - underwent significant cleanup and deconstruction, aimed at their declassification.



Aerial view of Grenoble

SILOETTE (INB 21)

Was an experimental pool-type reactor with power of 100 kilowatts; it was commissioned in 1964 and shut down in 2002. Two pools were used to store fuel and water from the site's three reactors. The reactor was designed for studying Siloé core physics (core configurations, fuel element efficiency measurements, neutron studies). Starting in 1973, it was also used to train workers who would operate EDF power reactors and CEA research reactors.



MELUSINE (INB 19) AND SILOÉ (INB 20)

MELUSINE (INB19) was an experimental pool-type reactor with

power of 8 megawatts; it was commissioned in 1958 and shut down in 1988. Siloé (INB20) was an experimental pool-type reactor with power of 35 megawatts; it was commissioned in 1963 and shut down in 1997. The two reactors were used in the following areas:

fundamental research on crystal structures, using neutron beams;

scientific support for the French nuclear fleet;

 studies of the behaviour of nuclear structures and fuels for the future;

- production of radionuclides for healthcare;
- production of doped silicon for microelectronics industries.



LAMA (INB 61)

Was the analysis laboratory for radioactive materials, commissioned in 1961; its capacity was doubled in 1965 for post-irradiation studies of uranium- and plutonium-based fuels and structural materials in nuclear reactors. LAMA ceased its activities in December 2002. The laboratory building has two parts:

• The first contains a chain of six concrete enclosures that have a very high level of radioactivity;

• The second part consists of five cells with lead shielding, with a high radioactivity level, and five specialised laboratories containing chains of lead cells.



• STED (INB 36 AND 79)

Was the effluent and waste treatment station, consisting of two basic nuclear facilities. Various operations were performed: compaction of solid waste, cementation of intermediate-level waste, incineration of organic liquids (oils and solvents), characterisation of solid waste, storage before transfer of waste to Andra.



2 **Requirements of the dismantling project**

The project extended over a period of 14 years, with several administrative steps that called for technical management of the project combined with budgetary and human resource management.

At the end of 2014, all the operations planned at project start to meet the ASN final-state requirements for declassifying the four basic nuclear installations had been completed.

The Siloette, Mélusine and Siloé reactors were declassified and demolished. STED and the Lama hot laboratory are in the final process of declassification. All the STED buildings have been demolished and clean-up operations have been performed on the soil.

Production of radioactive waste

The cumulative production of waste at the end of the project breaks down as follows:

Туре	Quantity (tonnes)	Destination	
Waste ILW-LL	8	CEA Cadarache CEA Saclay	
Waste	~850	Andra/CSA	
LILW-SL	~130	Socodei (Centraco)	
VLLW	~25,000	Andra/Cires	
Conventional waste	~25,000	CEA Grenoble (demolition rubble managed on site)	

All VLLW and LILW-SL from the dismantling sites was transported to the surface disposal facilities.

Project costs

The project was completed with a budget of 350 million euros. The breakdown is as follows:

Dismantling:	49%
Waste management:	22%
Operation:	21%
Project management:	8%



Conclusion

The three CEA-Grenoble reactors were cleaned up then demolished. The three hectares of land on which they stood will be reused for research and development on biomass. Cleanup work on the analysis laboratory for radioactive materials and on the two effluent treatment facilities has been completed. The administrative procedure for declassifying the last basic nuclear installations is in progress.

According to the CEA, this project demonstrates the capacity of the French nuclear sector to "close the loop" in a safe manner.

The CEA now has a complete set of technical-economic feedback data that it can use for its other dismantling projects. This experience feedback is also a basis for the CEA's assessment of the objective link between the costs of the operations to achieve the targeted final cleanup and the gains in terms of health and environmental impact.

Deconstruction of Chooz A nuclear power plant

Background 1

In France, the reference scenario adopted by EDF since 2001 has been deconstruction without a waiting period, in compliance with French regulations calling for a deconstruction "in as short a time period as possible between decommissioning of the facility and its dismantling" (see the Order of 7 February 2012 which sets the general rules for basic nuclear installations).

The regulatory process for deconstruction is framed by the French Environment Code. For a given site, it entails:

a single authorisation order for deconstruction, following an assessment issued by the French Nuclear Safety Authority (ASN)

key meetings with ASN, integrated in a safety reference framework for the decommissioning and dismantling operations;

a process of internal authorisation based on an operator's independent organisation and audited by the regulator to allow minor modifications impacting nuclear safety without having to gain authorisation from the regulator;

 preliminary phases prior to obtaining the authorisation order; during these phases:

- the operator must provide, at least three years before decommissioning, an application to its supervisory authorities and ASN (Article 37 of Implementing Decree 2007-1557) in which the declassification actions are specified (Article 40 of Implementing Decree 2007-1557),
- public consultations and enquiries must be organised (Article 38 of Implementing Decree 2007-1557).

2 EDF management of waste generated by deconstruction

The waste from deconstruction is sorted and is generally compacted and conditioned, before being transported to the appropriate disposal facilities. To ensure human and environmental protection during deconstruction operations, EDF strictly applies the same safety and radiation protection rules as those used for operation of its nuclear fleet.

In total, the deconstruction of the nine decommissioned reactors will generate around 800,000 tonnes of conventional waste, i.e. non-radioactive waste that will be recycled, and around 180,000 tonnes of radioactive waste (150 tonnes of ILW-LL, 17,000 tonnes of LLW-LL (graphite), 53,000 tonnes of LILW-SL, and 115,000 tonnes of VLLW).

Example of Chooz A: deconstruction of first pressurised water reactor

Located in the Ardennes department in northeastern France, on the Meuse River, the Chooz power plant has two operational reactors (Chooz B1 and B2) and a reactor undergoing deconstruction (Chooz A). Chooz A is one of the nine reactors currently in the deconstruction phase in France. Commissioned in 1967, Chooz A operated until 1991. It was the first pressurised water reactor (PWR) in France and resulted from a partnership between EDF and a group of Belgian producers who decided to create SENA, a nuclear power utility. What makes Chooz A unique is that its reactor and main nuclear auxiliaries are installed in the rocky caves of a hillside. Today, EDF is the nuclear operator of this facility.

Operations already completed

1991-1999: monitored closing of the facility:

- · pipework emptied,
- · spent fuel assemblies transferred to the reprocessing plant,
- operating waste removed,
- · dismantling of materials in the machine room.
- 1999-2008: partial dismantling of installations,
 - demolition of the machine room,
 - · disassembly, cleanup and demolition of the hill's nuclear buildings,
 - · rehabilitation of changing rooms,
- · dismantling of installations in main galleries,
- dismantling of gallery linking the back of the cave with facilities on the hill.

Operations in progress

2008-2014: dismantling of nuclear systems (excluding pressure vessel):

- · cutting of secondary system
- cutting off of reactor coolant system; removal and decontamination of steam generators,
- · decontamination of reactor coolant system and pressuriser,
- removal of steam generators as single waste items to the Andra disposal facility.

With the removal of nuclear fuel and the emptying of the various systems, **99.9% of the plant's radioactivity has been removed from the site**. The last dismantling phase for Chooz A, started in 2008, was authorised by a **complete dismantling authorisation order**, obtained in 2007 following a public enquiry conducted in 2006.





6 Next deconstruction steps

• dismantling of the pressure vessel in the reactor cave: after the dismantling of the reactor coolant system and its auxiliaries (in progress), the dismantling of the reactor pressure vessel and its internal structures will begin. These operations will mainly involve underwater cutting (shears, bandsaw, etc.);

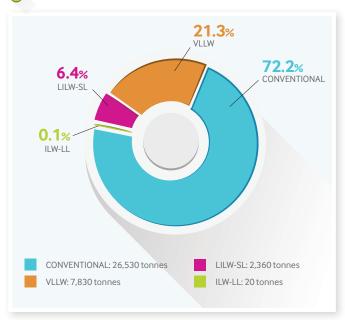
cleanup and remediation of the site:

the last equipment items in the nuclear auxiliaries cave and in the effluent treatment station will be dismantled. The buildings of the exterior platform will then be cleaned up and demolished, and the site will be entirely remediated.



WASTE PRODUCED AT THE CHOOZ A SITE

Waste classification	Total mass of waste to be produced from the Chooz A dismantling operation (t)	Cumulative mass of raw waste removed at the end of 2014 (t)	% waste removed
ILW-LL	20	/	0
LILW-SL	2,360	485	20
VLLW	7,830	3,440	45



WASTE PRODUCED AT THE CHOOZ A SITE

2. **REMEDIATION** SITES CONTAMINATED BY RADIOACTIVITY

ANDRA'S ROLE AND PUBLIC SERVICE ACTIVITIES

As part of its public service activities, Andra is tasked by the French government with rehabilitating "orphan" sites contaminated by radioactivity. These are sites where the producer of the contamination no longer exists and thus cannot take on the responsibility and costs of decontamination, in application of the "polluters pay" principle.

Most of these are old sites linked to the history of radium. From its discovery in 1898 by Marie Curie to the end of the 1950s, radium was used in numerous applications, some of them scientifically founded, for example in medicine and watch-making, and others less so, for example in cosmetics, fertilisers and for lightning rods. Public demand for radium-based products led to the building of plants, factories and even small urban workshops. When this "craze for radium" came to an end, these sites were reused without prior decontamination, or with measures considered insufficient by today's standards. In this context, Andra does work on industrial sites and in apartments and complexes that, over 70 years ago, housed companies which handled radium and are no longer in existence.

Andra also does work on old sites where the contamination is due to what is commonly referred to as "high natural radioactivity". An industrial activity may lead, as an unintended consequence, to residues in which the radioactivity naturally present in certain ores is concentrated. This is the case for old plants that produced cerium, titanium, phosphates, etc.

Cleaning up the buildings entails removing the contaminated construction materials: flooring, concrete slabs, ducts, etc. In rare cases, actual demolition may be necessary. As for the soil, the contaminated material is excavated until a residual level of radioactivity is found that does not pose a risk for current or future users of the site.

The waste produced is mainly VLLW, which is sent for disposal to the Cires facility, specialised for this type of waste. In rarer cases, LLW-LL can also be produced. This waste is also sent to Cires, but for temporary storage, pending the opening of a suitable disposal facility.

Given the typology of sites treated by Andra, the waste produced is mainly rubble, soil, wood and technological waste (work clothing, tools, etc.).

This waste is conditioned in big bags or injectable metal containers, sometimes after having been temporarily placed in smaller drums. Since some of the sites are located in urban areas (most of these sites are in Paris or its environs), it may be necessary to first use 120 L shuttle drums, easy to handle in Parisian apartments and stairways. Transported on a storage platform, these drums are then emptied and the waste conditioned in its definitive packaging.

In certain cases, managing the waste is more complex due to the presence of chemical pollutants, asbestos or radioactive liquid products.

EXAMPLE OF ANDRA REMEDIATION SITE

Focus on the cleanup of two plots at Gif-sur-Yvette

In the beginning of the 1900s, the Société Nouvelle du Radium was created in the town of Gif-sur-Yvette. The company included:

• A radioactive substances testing laboratory (LESR) located in the Coudraies neighbourhood;

• A radium extraction plant located in the adjacent Clos Rose neighbourhood.

The plant operated between 1913 and 1935. Since then and to this day, the site has always been used for industrial purposes.

The laboratory was in operation until the end of the 1950s. When it closed, the buildings were demolished to make room for a housing development; the soil had scattered zones of contamination.

Andra performed remediation work on two residential plots of this neighbourhood. Each of these plots had a house built in the 1960s on soil that was already contaminated, resulting in a radon level in the houses above the public health recommendations.

The preliminary technical and economic studies showed that it was not possible to remove the contaminated soil under the houses without demolishing them. The decision was thus made to buy the two plots from their owner and convert them to "green space" use.

The remediation work began in September 2013 and lasted a year. After the houses were demolished, the most contaminated soil was extracted and eliminated, and the low residual pollution present at the bottom was confined under a thickness of healthy soil varying from 50 cm to several metres. Use restrictions are in force in the neighbourhood to prevent digging below this layer of healthy soil.

In total, 339 m³ of VLLW and 0.2 m³ of LLW-LL were produced.



O Worksite 1 - Before remediation



Worksite 1 - After remediation (before sodding)



Worksite 2 - Before remediation



Worksite 2 - After remediation

REPORT 4

MANAGEMENT OF SPENT RADIOACTIVE SOURCES

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1. SPENT RADIOACTIVE SOURCES CONSIDERED AS WASTE

There are two types of radioactive source: sealed and unsealed.

DEFINITION: RADIOACTIVE SOURCES

Appendix 13-7 of the public health code defines a source as a "device, radioactive substance or installation capable of emitting ionising radiation or radioactive substances".

Unsealed radioactive sources: "Sources whose presentation and normal conditions of use do not allow the dispersion of radioactive substances to be prevented." These therefore present both the risk of radiation exposure (this goes for all sources) and that of contamination by contact, ingestion or inhalation. These sources can be liquid, solid, or gaseous.

Sealed radioactive sources: "A source whose structure or packaging prevents, in normal use, any dispersion of radioactive materials into the environment." Sealed sources are usually solid.*

*A source is considered sealed in France if it is compliant with the NFM 61 002 and NF 550 9978 standards.

The use of radioactive sources is regulated by the public health code, which stipulates in particular (Article L. 1333-7) that the supplier of sealed sources must take them back when they are no longer being used, or simply at the request of the user.

Spent sealed sources waiting for their final disposal solution are stored in appropriate facilities, which the supplier must possess.

Used sealed sources of foreign origin sold in France return abroad via their supplier. This arrangement is part of a contractual obligation between the foreign manufacturer, its supplier in France, and the safety authority, in application of the licence to distribute granted by the Institute for Radiological Protection and Nuclear Safety (IRSN) acting on the request of the French Nuclear Safety Authority (ASN).

Only sealed sources not reused by their manufacturer are considered as waste and listed in this inventory.

By their nature, unsealed radioactive sources cannot be recovered. Their use produces solid waste and radioactive effluent that is managed according to the usual channels for the management of radioactive waste and recorded in the national inventory as such.

ARTICLE R.1333-52 OF THE PUBLIC HEALTH CODE (modified by Decree 2015-231 of 27/02/2015)

A sealed radioactive source is considered to have expired ten years at the latest after the date of first registration marked on the supply form or, if none, after the date of its initial market introduction, unless an extension is granted by the competent authority.

Any holder of sealed radioactive sources that are expired or at end-of-life must have them retrieved, irrespective of their condition, by a supplier authorised to do so under the terms of Article L. 1333-4 of the Public Health Code. Sources that are not recyclable under the technical and financial conditions of the time may be retrieved, as a last resort, by Andra. The holder is responsible for the costs related to the retrieval of these sources. If the holder has its sources retrieved by a supplier other than the original one, or if they are retrieved by Andra, the holder must send a copy of the retrieval certificate issued by the retrieval agent to the original supplier and to the Institute for Radiological Protection and Nuclear Safety (IRSN) within one month of its receipt.

The supplier of sealed radioactive sources, or products or devices that contain such sources, is under an obligation to retrieve, unconditionally and on request, any sealed source it has distributed, must notably when that source is expired or when its holder can no longer use it. When the source is used in a device or product, the suppler is also obliged to take it back in full if the holder so requests. The supplier declares to the ASN and IRSN any failure to return any sealed source it has distributed, or product or device containing one, to itself, another supplier, or Andra within the required time limits.

Any supplier may either dispose of or arrange the disposal of the retrieved sources in a facility authorised for that purpose, or return them to their supplier or the manufacturer. The supplier must have a storage site whose conditions are compatible with health and safety protection regulations, and whose capacity is sufficient to accommodate end-of-use sources during the period preceding their disposal or recycling.

2. WASTE PRODUCED BY THE USE OF UNSEALED SOURCES

USE OF UNSEALED SOURCES



In the field of research, they are used as a marker for molecules or a radioactive tracer. The most commonly used radionuclides are:

• for very short half-lives: phosphorus-32 and -33, sulphur-35, chromium-51, and iodine-125;

- for short half-lives: tritium;
- for long half-lives: carbon-14.

In the fields of cellular and molecular biology, hydrogeology, and other fields of study concerning physical-chemical mechanisms, they are used to mark the molecules in which they are incorporated in order to track the dynamics of living mechanisms.



Unsealed sources are widely used in the medical field for diagnostic purposes and in certain treatments.

3 Applications in *in-vitro* diagnosis

Radiography analyses, carried out in laboratories generally linked to a nuclear medicine department, enable bioassays to be made on samples.

These applications become essential when conventional assay techniques reach their limits, for example, if the content of the substance being assayed is low or because of its chemical complexity. The radioactivity of the products marked by radionuclides allows them to be detected at levels that would not be accessible by chemical analysis.

The main radionuclides used are tritium, phosphorus-32 and iodine-125, among others.

Many laboratories also carry out radio-immuno-assays. This is a very precise assay technique using radioactivity, which measures the concentration of biological substances such as enzymes, hormones, and other molecules in the blood, urine, and saliva for example.



Applications in *in-vivo* diagnosis

Various medical imaging diagnostic applications make direct use of radioactivity's properties: These techniques are used to locate and examine body organs (anatomical medical imaging), or visualise how they are working (functional medical imaging).

In isotope scanning, when a radiopharmaceutical is administered to the patient, a detecting device tracks the marker in the body, for example to create a dynamic internal image of an organ. The operator then works out how the organ functions by interpreting the images obtained and provides what is known as an in vivo diagnosis.

Radionuclides are widely used for bone, thyroid, cardiac and lung scans, etc.

The most commonly-used radionuclides include metastable technetium-99, thallium-201, iodine-131, iodine-123 and gallium-67 (see the table below).

Tomography techniques (techniques used to reconstruct the volume of an object from a series of measurements made by slice from the outside of that object) are also based on the properties of the x-rays or gamma rays.

Fluorine-18 positron emission tomography is now increasingly being used for applications in the fields of neurology, cardiology and oncology.



Radiotherapy machine

5 Therapeutic applications

Therapy applications using unsealed sources are based on selective cell destruction, *thanks to* the use of a radiopharmaceutical product in liquid or capsule form.

The capsule contains a radionuclide that fixes itself lastingly and specifically to the organ or tissue to be irradiated.

The aim of this technique, called metabolic radiotherapy, is to destroy the cancer cells and preserve the maximum number of healthy cells.

Some techniques demand specific radionuclides conditioned in particular ways (iodine-131 in capsules, iridium-192 in wires).

PAIN RADIONUCLIDES USED IN THE MEDICAL FIELD (LISTED IN ORDER OF INCREASING MASS NUMBER, WITH INDICATION OF THEIR RADIOACTIVE HALF-LIFE).

Radionuclides	Name	Radioactive half-life
ЗΗ	Tritium	12.33 years
¹⁴ C	Carbon-14	5,700 years
¹⁵ O	Oxygen-15	2.04 minutes
¹⁸ F	Fluorine-18	1.83 hours
²² Na	Sodium-22	2.6 years
³² p	Phosphorus-32	14.27 days
³³ p	Phosphorus-33	25.38 days
³⁵ S	Sulphur-35	87.32 days
⁵¹ Cr	Chromium-51	27.7 days
⁵⁷ Co	Cobalt-57	271.8 days
⁵⁸ Co	Cobalt-58	70.86 days
⁶⁷ Ga	Gallium-67	3.26 days
⁶⁸ Ga	Gallium-68	1.13 hours
⁶⁸ Ge	Germanium-68	270.95 days
^{81m} Kr	Krypton-81 (metastable*)	12.8 seconds
⁸¹ Rb	Rubidium-81	4.58 hours
⁸⁸ Y	Yttrium-88	106.63 days
⁸⁹ Sr	Strontium-89	50.57 days
90Y	Yttrium-90	2.67 days
⁹⁹ Mo	Molybdenum-99	2.75 days
^{99m} Tc	Technetium-99 (metastable*)	6.01 hours
¹¹¹ In	Indium-111	2.80 days
123	lodine-123	13.22 hours
125	lodine-125	59.41 days
131	lodine-131	8.02 days
¹³³ Xe	Xenon-133	5.24 days
¹³⁷ Cs	Caesium-137	30.04 years
¹⁵³ Sm	Samarium-153	1.93 days
¹⁶⁹ Er	Erbium-169	9.40 days
¹⁸⁶ Re	Rhenium-186	3.78 days
^{186m} Re	Rhenium-186 (metastable*)	1.996 x10 ⁹ years
¹⁹² lr	Iridium-192	73.82 days
²⁰¹ TI	Thallium-201	3.04 days
²²⁶ Ra	Radium-226	1,600 years
²²⁷ Ac	Actinium-227	21.77 years

Source: JEFF 3.1.1. decay data library (OECD - NEA)

* Metastable: state in which an atomic nucleus is "locked" in an excited state (at a higher energy level than its fundamental state) for a certain period, from a few billionths of a second to several billion years.

MANAGEMENT OF WASTE PRODUCED BY THE USE OF UNSEALED SOURCES



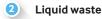
Solid waste consists of empty bottles that have been used to hold radioactive liquids and small items of laboratory equipment (tubes, glassware, gloves, syringes, needles, soiled cotton wool).

This waste is collected in appropriate containers for the radioactive risk.

• Very short-lived waste is placed in them before removal after decay of its radioactivity (half-life less than 100 days).

It is then directed to the conventional waste disposal firms once final measurements have been made of any residual radioactivity.

• Waste that cannot be managed in this way (half-life longer than 100 days) is sent to an Andra disposal facility.



Aqueous liquid waste from laboratories or hospitals is collected in tanks and stored on site.

If this waste has a half-life of less than 100 days, it is left in situ to allow it to decay.

If these effluents contain radionuclides with a half-life longer than 100 days, they are collected and treated by incineration at the Centraco treatment centre. The ash and solid clinker resulting from the incineration are packaged and then stored in Andra disposal facilities.

These activities also lead to the production of contaminated solid waste (gloves, tubes, glassware etc.). The waste is managed like other waste produced by the use of unsealed sources.

3. WASTE PRODUCED BY THE USE OF SEALED SOURCES

In this case, the waste is itself the sources. These can have very different geometries and activities according to the sector in which they are used.

The first sealed sources appeared in the 1920s with, in particular, radioactive radium lightning rods (1932) and radium needles for medical applications.

Since the 1950s, sealed sources have used artificial radionuclides.

These sources are used in a variety of fields:

• sources for industrial, educational and research applications: irradiation for research and industrial programmes, nondestructive testing, density, level, thickness, and humidity gauges, etc., elimination of static electricity, analysis, calibration and chromatography;

• sources for medical applications: gamma beam therapy, brachytherapy, cardiac stimulators, anatomical marking, osteodensitometry, blood irradiation, etc.

Other types of source have been widely distributed and are not subject to individual tracking because they contain natural radionuclides or

radionuclides whose radioactivity is below the exemption thresholds defined in Appendix 13-8 of the public health code.

EXEMPTION THRESHOLD (EXCERPT FROM APPENDIX 13-8 OF THE PUBLIC HEALTH CODE)

The nuclear activities mentioned in a) and b) of Paragraph 1 of Article R. 1333-27 of the French Public Health Code can be exempted from authorisation when the quantity of concentration of the radioactivity of the radionuclides concerned does not exceed the values indicated in the table in the appendix.

These nuclear activities are as follows:

- manufacture of products or devices containing radionuclides,
- distribution of products or devices containing radionuclides,
- use of devices that emit x-rays or radioactive sources,
- use of accelerators other than electron microscopes.

SEALED SOURCES FOR INDUSTRIAL APPLICATIONS

The use of artificial radionuclides in the form of sealed sources associated with devices is common in the industrial sector.



Nondestructive inspection and testing of materials

This concerns the following cases:

 inspection of welds using gamma radiography (sources of iridium-192, cobalt-60, or caesium-137);

 detection of toxic products, such as lead in paints (sources of cadmium-109 or cobalt-57);

 detection and dosing of molecules in pesticides, explosives, or drugs using gas chromatography (sources of nickel-63 or tritium).

Measurement systems

Comprising an emitter unit (krypton-85, caesium-137, americium-241, cobalt-60, or promethium-147) and a radiation detector unit, these sources are used to determine the grammage of paper, fabric, plastic, or thin metal.

These devices are used in the paper industry and the tobacco industry, for example.

Control and monitoring the operation of nuclear power plants 3

These operations require the use of sealed sources, especially in:

 radiation protection measurement chains for the reactor control system, using sources of caesium-137, strontium-90, radium-226, or americium-241. Their radioactivity is less than 3.7 megabecquerels;

reactor power measurement systems using sources of americium and beryllium. Their radioactivity is less than 150 gigabecquerels (0.15 TBq).

Industrial irradiation

lonising radiation emitted by radioactive sources is used for its effect on living matter, particularly to:

 sterilise medical equipment and pharmaceuticals (destruction of micro-organisms);

preserve certain foodstuffs (destruction of micro-organisms and parasites),

- inhibit germination (e.g. of potatoes) using low dose irradiation;
- disinfest cereals and fruit;

slow down physiological decomposition processes using low dose irradiation;

perform industrial sterilisation of meat, spices and prepared foodstuffs using high dose irradiation.

SEALED SOURCES FOR MEDICAL **APPLICATIONS**

In the medical sector, radioactive sources are mainly used in two areas:

blood treatment: sealed radioactive sources are used to irradiate blood before a transfusion. This treatment inhibits the proliferation of lymphocytes and reduces problems related to the patient's immune system;

radiotherapy: there are four radiotherapy techniques-external radiotherapy, metabolic radiotherapy, radiosurgery, and brachytherapy. External radiotherapy or gamma beam therapy is based on gamma radiation from cobalt 60 sources.

The use of these sources is in decline and the use of electron linear accelerators producing high-energy x-ray beams and electron beams is on the rise.

Sealed sources used in radiotherapy have high activity levels, with radionuclides whose half-lives can last several years.

Radiosurgery is similar to external radiotherapy. It uses highly focused beams from a linear accelerator or a specialist irradiator (several cobalt 60 sources). This technique is nevertheless not very widespread.

In brachytherapy, the sealed radioactive source is placed inside the patient for a limited time or permanently, according to the case, in contact with or in immediate proximity to the area to be treated.



Gamma radiography device

The main radionuclides used (iridium-192, iodine-125, caesium-137, cobalt-60, palladium-103, and ruthenium-103) have permanently replaced radium (see inset below), which was used in the first half of the twentieth century in the form of needles and tubes. Their radioactive half-lives range from 17 days (palladium-103) to 31 years (caesium-137).

RADIUM-BEARING ITEMS

In the early twentieth century, the therapeutic benefits of radium in destroying diseased tissue were discovered. Thanks to some spectacular results, radium became very fashionable in the 1920s and 1930s.

In those days, many hygiene products, industrial products, etc. (powders, ointments, wools, animal feed, spark plugs for cars, fountains, etc.) were sold in France.

The manufacture, production and sale of radium-bearing items were banned at the end of the 1950s due to the radioactive hazards involved. By their very nature, most of those products were consumed (powders, ointments, animal feed, etc.). Others are still in existence, and still contain radium.

Radium-bearing items for medical use, such as needles, probes, and applicators used in the treatment of tumours, constitute most of the remaining sources, and are potentially recoverable.

The Central Service for Protection against Ionising Radiation (SCPRI) in 1985, which became the Office for Protection against Ionising Radiation (OPRI) together with Andra in 1999 and 2000, recovered over 3,400 radium-bearing items for medical use from radiology practices, clinics and cancer facilities and particularly private individuals. This represents about 1.3 terabecquerels of radium. Some 2,800 radium-bearing medical items were collected during the first wave, a further 500 in the second wave, and a few dozen items recovered since. Other objects (tubes of ointment, radium fountains, etc.) are still gradually being collected by Andra to this day and being stored in the Aube, at the Cires waste disposal facility.

OTHER TYPES OF SEALED SOURCE

Lightning rods

In the early twentieth century, scientists had the idea of adding sealed radioactive sources to the heads of lighting rods to boost the natural ionisation of air. In those days, the scientific community believed that ionising the air around a lighting rod would make it more effective against lightning. Ionising lightning rods were manufactured in France from 1932 to 1986 by Helita, followed by Duval Messien, Franklin France, and Indelec. Many of them were sold in other countries. Because their additional effectiveness was not proven, the Order of 11 October 1983, applicable from 1 January 1987, prohibited their manufacture.

The total number of lighting rods installed in France is estimated at 50,000, of which 30,000 are equipped with sealed radium-226 sources (or both radium-226 and americium-241 sources at the same time: mixed lightning rods), and 20,000 are equipped with sealed americium-241 sources (see inset on following page).

The radioactivity of a radium-226 lightning rod is around 50 megabecquerels, and that of an americium-241 lighting rod is around 20 megabecquerels.

Radioactive substances come in the form of sintered pellets, plates, sheets, or balls made of painted porcelain, which are generally small.



Radium-tipped lightning rod

LIGHTNING RODS

An estimated 50,000 radioactive lightning rods are believed to have been sold in France. There is no law requiring their elimination.

However, every time one is dismantled, it must be removed as an item of radioactive waste.

These lightning rod heads are stored together in temporary facilities by professional firms approved by the safety authority.

Andra issues a (non-exhaustive) list of such firms to owners of a lightning rod. It should be noted that the activity of collecting and storing radioactive lightning rods is subject to authorisation by the French Nuclear Safety Authority (ASN).

Andra collects around 500 to 600 lightning rod heads per year. Lightning rods containing radium-226 were previously sent to the CEA's Cadarache Centre to be compacted and packaged in 870-litre drums pending disposal. Since 2011, they have been sent to the Andra storage platform at the Cires facility pending the creation of a disposal system.

Americium-241 lightning rods are packaged in 200-litre drums and then stored on a special Andra platform at Cires. The permanent packaging solution and disposal system for these lightning rods is still being studied.

3



The most common model of smoke detector in France is the ionisation detector. It uses the properties of small sealed sources.

The source ionises the air in the device. When smoke enters it, electrical conductivity drops, thus setting off the alarm. The number of smoke detectors equipped with sealed radioactive sources installed in France is usually estimated at around 6 to 8 million. In general, these detectors contain a source of americium-241 with radioactivity of around 30 kilobecquerels. The unit activity of certain recent sources has dropped by around 10 kilobecquerels or less. Certain detectors use radium-226 or plutonium-238 sources. These detectors are prohibited for domestic use but are often used in office blocks and public buildings.

The order of 4 April 2002 (public health code) restricts the commissioning of devices containing radioactive materials. Provisions have therefore been implemented for the gradual replacement of ionisation detectors with optical detectors.



Smoke detector with sealed radioactive source

Radioluminescent objects bearing radium-226 and tritium

Radium paints were used up until the 1960s. Radioluminescent paint contained zinc sulphide mixed with linen oil and radium, and was used for applications related to night vision in the clockmaking industry (alarm clocks and clocks), aeronautics, and armies (compasses, signposting, aiming devices, dials, etc.).

The radium was gradually replaced by tritium, a radionuclide with a shorter half-life and which is much less toxic. Now tritium in turn is largely replaced by (non-radioactive) photoluminescent paints whenever possible.



Surge protectors and electronic vacuum tubes

in the 1960s and 1970s, lightning rods or surge protectors and electronic vacuum tubes (ancestors of the transistor) containing radionuclides in gaseous form (such as krypton-85) or paint (such as tritium or radium-226) were used as a filter to protect electrical installations from brutal overvoltages.

A very large number of these sources was produced. Some years, as many as a million copies were produced.

They were essentially used for the production of electronic equipment (such as radar) and equipment for the telephone network.

Today, a few nickel 63 electronic vacuum tubes are still being produced to protect radar devices.



Smoke detectors with sealed radioactive sources are **prohibited** in France for any **domestic use**.



Other historic sealed sources

All of the sealed sources described above were produced on a large scale: thousands or millions of copies.

Other sealed sources were produced in small quantities in the twentieth century. These have atypical characteristics.

Examples:

 strontium-90 isotopic generator sources for electricity production, of which there are around 10, are very highly radioactive and are stored at some NPPs:

• cardiac stimulator or "thermopile" sources of plutonium 238, of which around 3,000 were manufactured by the CEA between 1968 and 1976 and stored on the CEA site at Saclay.

THE MAIN MANUFACTURERS OF SEALED RADIOACTIVE SOURCES IN FRANCE

The French Alternative Energies and Atomic Energy Commission (CEA) - the historic manufacturer

The CEA was the main manufacturer of sealed sources in France.

This production was initiated by the Radioelements Department and gradually diversified into other CEA departments, particularly the Transuranics Department (especially neutron sources) and the Department for Applications and the Metrology of Ionising Radiation (DAMRI).

This department consisted of several laboratories, including the ionising radiation measurement lab (LMRI), which mainly manufactured and sold calibration standards, and the Radiation Applications Unit (SAR), which was and remains the designer and distributor of industrial gauges.

In 1985, the CEA decided to divest itself of some of those activities. CIS Bio International, a subsidiary of the CEA at that time, undertook the manufacture and sale of industrial and medical sources. LMRI continued manufacturing calibration sources and remained the reference laboratory.

The CEA gradually wound down its manufacturing activities in this field.

In 1999, the Radioactivity Standards Laboratory (LEA) run by CERCA (Company for the study and manufacture of atomic fuels, AREVA Group) purchased the LMRI's catalogue and processes.

CIS Bio International

Now belonging to the Belgian group IBA (Ion Beam Application), CIS Bio International has the POSEIDON irradiator, which includes irradiation devices for biomedical and industrial products.

In 2000, CIS Bio International halted the production of industrial sealed sources to focus on the manufacture of unsealed medical sources and radiopharmaceutical products containing short half-life radionuclides. The company then moved towards the manufacture of radionuclide substitutes for diagnostic and therapeutic applications and for the pharmaceutical industry.

CIS Bio International stores spent sealed sources on its site at Saclay, for its own purposes and for the CEA. In 2009, the CEA and CIS Bio International created GIP Sources HA, whose main aim is to collect and dispose of, within 10 years, sources of cobalt-60 and caesium-137 distributed by the CEA or CIS Bio International.

The Radioactivity Standards Laboratory (LEA)

This is the only high-volume manufacturer of sealed sources in France and is located at the Pierrelatte site.

LEA belongs to the AREVA Group and has an annual output of about 400 sources, all types taken together. The commodities needed to manufacture calibration sources are high activity solutions or solid or gaseous products, produced in reactors or particle accelerators.

Other manufacturers or suppliers

In addition to these manufacturers, there are a few other companies that supply sources. In certain cases, the are also the manufacturer of the equipment containing the sources or have source production and recovery capabilities outside France:

 maintenance, source compliance monitoring, equipment decontaminating firms (CETIC, CERAP, Intercontrôle, Saphymo, SGS Multilab, Elta, etc.);

Thalès which still manufactures electronic vacuum tubes;

companies that own transit zones for foreign manufacturers' sources (Healthcare, formerly Amersham, for example).

4. INVENTORY OF SPENT RADIOACTIVE SOURCES CONSIDERED AS WASTE

Waste generated specifically by the use of unsealed sources is not distinguished from other radioactive waste.

On the other hand, spent sealed sources considered as waste are subject to a special inventory in accordance with the data available in the IRSN database as part of the inventory of sealed sources.

As of 31 December 2013, approximately 2,300,000 spent sealed sources or radioluminescent objects had been listed.

The quantities of packages calculated in the table opposite are only an estimate based on the evaluation of stocks for each holder and a simplified calculation of the number of packages required to manage these sources as radioactive waste.

These evaluations fall within the framework of the work areas defined in the National Radioactive Materials and Waste Management Plan.

	CONSOLIDATED INVENTORY FOR ALL HOLDERS
· · ·	CONSOCIDATED INVENTION TO CALE TO EDENS

Disposal solution	Type of disposal package	Number of packages (stock)
VLLW (Cires)	1 m ³ basket	6
LILW-SL (CSA)	5 m ³ package	31
	870 I package	78
MA-VL (Cigeo) or LLW-LL	CSM packages stored by the CEA	41
HA (Cigeo)	CDT 175 I	6

.....TRACKING OF RADIOACTIVE SOURCES

Prior to 2002, the use of natural radionuclides was regulated only by the Labour Code, whilst the use of artificial radionuclides was additionally regulated by the Public Health Code since the early 1950s via the Interministerial Commission for Artificial Radioelements (CIREA).

An authorisation regulated all practices involving artificial radionuclides (manufacture, sale, distribution, storage, use) and, over the years, a limited duration of use (10 years) was set¹. From that time onwards, special conditions of use were set. This applies to sources that cannot be returned after ten years (implanted medical sources, sources in a reactor, etc.) and sources not requiring authorisations (radioactivity below the exemption thresholds defined in Appendix 13-8 of the public health code, holding without authorisation subject to observance of specific requirements, etc.)

However, sources containing natural radionuclides (such as radium) did not need authorisations because their use was not regulated by the public health code.

Since 2002, the authorisations required by the public health code are issued by the competent authorities: prefectures, the French Nuclear Safety Authority (ASN), etc.

The Institute for Radiological Protection and Nuclear Safety (IRSN) records the movements of these sources in France (authorisations to market sources and their return to the distributor) and keeps a current inventory.

This National Inventory centralises the authorisations issued by the various competent authorities for radioactive sources and the movements of sources in France (acquisition, transfer, export, import, recovery, replacement, etc.).

This enables the source to be located, gives information on its radionuclide, its radioactivity level on a given date, the date the licence was granted to use it, the name of the manufacturer, the supplier, and the user organisation and its use.

It is thus possible to know the number and use of every sealed source at any time (around 40,000).

For more information: www.irsn.fr

1 The 10-year period in use was set when the distribution of radioactive sources was linked to a financial guarantee for their return to the distributors

(a financial guarantee must include the scope of the guarantee, an amount, and an expiry date).

REPORT 5

WASTE WITH HIGH NATURAL RADIOACTIVITY

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INTRODUCTION

Waste with high natural radioactivity, which includes technologically enhanced, naturally occurring radioactive material (TENORM) waste, is generated by the transformation of raw materials that contain naturally occurring radioactive material (NORM) but which is not used for their radioactive properties. These radionuclides can be found in materials or waste and may require special management.

1. REGULATIONS AND THE MANAGEMENT OF WASTE WITH HIGH NATURAL RADIOACTIVITY

Certain industries other than nuclear power use manufacturing processes that sometimes lead to using or concentrating natural radioactivity.

According to its history, its level of radioactivity, and the half-life of the radionuclides it contains, this waste can be classified in four categories:

• LLW-LL-type waste with high natural radioactivity: this is radiumbearing waste, which means that it contains natural radionuclides with a long half-life, particularly radium and/or thorium. Their final disposal solution is currently being studied. Sites that store this type of waste are subject to record sheets in the Geographical Inventory;



Port de La Pallice à La Rochelle

 VLLW-type waste with high natural radioactivity: this waste goes to the VLLW disposal facility in Aube. Waste stored on site pending handling is also subject to record sheets in the Geographical Inventory;

• waste with high natural radioactivity disposed of in situ: this waste was disposed of, at the time of its production, in disposal facilities not operated by Andra. Some VLL waste was used as backfill (e.g. at the site of La Rochelle) or disposed of in internal waste disposal facilities (e.g. heaps of phosphogypsum). This historic disposal facilities are subject to sheets in the part dedicated to historic sites in the Geographical Inventory;

• waste sent to conventional waste disposal facilities: the regulations allow for the possibility of storing waste with high natural radioactivity in conventional disposal facilities.

Moreover, certain residue from industrial processes with high natural radioactivity is recovered and is not subject to a declaration to the national inventory but is presented in this file: that is what happens with coal ash.

THE MANAGEMENT OF WASTE WITH HIGH NATURAL RADIOACTIVITY IN WASTE DISPOSAL FACILITIES

Until 2005, there were no specific regulations for this type of waste. In 2005, an order concerning "professional activities involving raw materials naturally containing radionuclides not used because of their radioactive properties" was published. This order stipulates that any operator of an installation covered by Appendix 1 of the order must provide the French Nuclear Safety Authority (ASN) with a study intended to estimate the dose received by the population because of the installation [1].

The circular of 25 July 2006 provides a strict framework for the management of "waste containing radioactive substances whose radioactivity or concentration cannot be neglected from a radiation protection point of view."

The operator of the disposal facility must attach an impact study specific to the radiological risk to any waste handling request for waste with high natural radioactivity submitted to the relevant prefect [II].

This type of study is codified. It must be drawn up in accordance with the technical guide published by the ministry responsible for the environment and IRSN in 2006 [III].

The impact study must show that the impact of storing this waste is negligible from a radiation protection standpoint, both for the operating personnel and for the neighbouring population, including over the long term. The circular also stipulates that this management mode is intended only for limited, clearly identified and characterised batches of waste. Periodic statements, including those concerning any waste with high levels of natural radioactivity, must be submitted to the monitoring committees of the disposal facility sites (CSS, EX-CLIS) to keep the surrounding population properly informed. The Circular of 18 June 2009 [IV] strengthens the HCTISN recommendations, particularly concerning provisions for monitoring and disclosing information about disposal sites containing waste with high natural radioactivity.



Storage of packaged radium-bearing waste



Storage of loose radium-bearing waste

Order dated 25 May 2005 (Official Journal 126 of 1 June 2005) concerning professional activities using raw materials that naturally contain radionuclides not used because of their radioactive properties.

[[]II] Circular of 25 July 2006.

^[11]] Methodological guide for the acceptance of waste with natural radioactivity in classified disposal facilities DEI/SARG/2006-009. Circular of 18 June 2009 concerning the imple-

[[]IV] mentation of the recommendations of the High Committee for Transparency and Information on Nuclear Safety.

2. **INDUSTRIAL SECTORS** AND WASTE PRODUCED

It is hard to make an exhaustive list of all the industries likely to produce this type of waste with high levels of natural radioactivity. A typology of the industries currently likely to produce this type of waste has been drawn up and is divided into two parts: the manufacturing sectors listed in Appendix 1 of the Order of 25 May 2005 and the sectors not concerned by this order. This list is based on known feedback from present or past industrial practices and on two reports published by the ASN in 2009 [V] based on studies carried out by the Robin des Bois Association [Vi].

Moreover, the ministry responsible for the environment carries out national monitoring of the waste management statement.



For the 2015 edition of the national inventory, industries subject to the Order of 25 May 2005 were surveyed. Moreover, industries other than those listed by the order were identified by Andra as being likely to produce waste with high natural radioactivity and were also asked. Despite this, the inventory cannot claim to be exhaustive.

INDUSTRIAL SECTORS CONCERNED BY THE ORDER OF 25 MAY 2005.

Industries for the processing and transformation of tin, aluminium, copper, titanium, niobium, bismuth and thorium ore

The ores concerned sometimes contain radionuclides that are concentrated in the residue. These radionuclides can be of the same chemical nature as the metal extracted (radioactive thorium, bismuth, or niobium mixed with the metal in stable form) or different chemical elements.

In the field of the extraction of rare earth elements, the Solvay site at La Rochelle used monazite to produce thorium hydroxide. This production generated LLW-LL type radium-bearing residues (approximately 6,400 m³), most of which has been sent to a CEA storage facility at Cadarache.

Moreover, common solid waste that has a very low radioactivity level is stored on site and constitutes part of the backfill of La Pallice harbour. This is legacy waste.

Finally, around 10,000 m³ of LLW-LW RSB is stored on site: this is the biggest share of waste with high natural radioactivity of the LLW-LW type. Studies are currently being conducted to determine how to process this waste in order to extract the rare earth elements from it.

Overall, the quantity of packaged radium-bearing residues and common solid waste has increased by around 3000 m2 since the 2012 edition. This change does not however correspond to an increase in the quantity of radioactive waste, but rather a change in the assumptions concerning the packaging of radium-bearing waste.

Moreover, the chemical industry extracts colouring pigments, mainly for paints, such as titanium dioxide, from natural ores or sands. The initial thorium and uranium radioactivity levels may be concentrated in the process residue. Cristal Global manufactured titanium dioxide on the Thann and Ochsenfeld sites and on its site at Le Havre. The categories of waste produced are VLLW (approximately 1820 m³) and LLW-LW (approximately 210 m³).

Alumina is extracted from bauxite, which generates deposits of red sludge (rich in iron oxide) on the site; this most notably contains radium. This type of storage (a little more than 8 million tonnes) is found on the Aygalade, Barasse-Montgrand, Barasse-Saint-Cyr and Vitrolles sites in the Bouches-du-Rhone department. Alteo operates the Gardanne site.

Likewise, Tioxide Europe manufactures titanium dioxide pigments whose production generates waste on the Calais site that can be evacuated to waste storage facilities in accordance with the 2006 circular.

M ASN report of 20 July 2009 "Statement concerning management of waste containing technologically-enhanced radioactivity" and ASN report of 24 December 2009 "Assessment of ionizing radiation exposures in industries and professional activities implementing raw materials containing naturally-occurring radionuclides not used because of their radioactive properties: Review on enforcement of Order of 25 May 2005 on these activities."

[[]VI] Robin des Bois reports: "Technologically-enhanced natural radioactivity" (2005) and "Coal ash and phosphogypsum" – supplements (2009).

Industrial	Management solu- tion	Volume (m³)
CEA (storing waste for Solvay)	LLW-LL	6,128
Cristal Global	VLLW	1,823
Cristal Global	LLW-LL	209
Solvay	LLW-LL	10,284
Tioxide Europe	conventional waste disposal facility	75

Refractory ceramic production industries and glassmaking, foundry, steel, and metallurgical activities.

Refractory ceramics owe their natural radioactivity mainly to the presence of zircon. Variations in its quantity make the radioactivity of the ceramic vary:

 Savoie Réfractaire (a company in the Île-de-France and the Rhône-Alpes regions), which belongs to the Saint-Gobain group, produces ceramic coatings for various industries. The waste, which consists of zircon sand, is disposed of in a conventional waste storage facility;

 Thermal Ceramics de France, a company producing ceramic fibres from zircon sand; the waste generated by the process is disposed of in a conventional waste disposal facility;

• Imeyris, a company located in Ploemeur (56), extracts and manufactures ceramic materials from kaolinic materials. Most of the waste produced is stored at a waste disposal facility, except for a small volume whose impact study has shown that it should be disposed of at the VLLW Disposal Facility, located in Aube.

Industrial	Management solu- tion	Volume (m³)
Société Savoie Réfractaire, Saint-Gobain Group	conventional waste disposal facility	5
Thermal Ceramics de France	conventional waste disposal facility	18
Imerys Ceramics France	VLLW	6

Industries that manufacture and use zircon and baddeleyite, primarily the refractory ceramics and abrasives industries

Zirconium is used in alloys for nuclear fuel cladding:

• Cezus produces the raw materials required for the manufacture of the alloy and generate radium-bearing LLW-LL as well as waste that will be disposed of at the VLLW disposal facility, located in Aube; • Comptoir des Minéraux et Matières Premières in Saint-Quentin, which processes zircon sand with a view to its use in a foundry, currently stores a small quantity (3 m³) of waste intended to be disposed of in conventional waste disposal facility in 2014;

 SNECMA Gennevilliers uses zircon flour in the foundry procedure for aircraft engine parts. The waste generated is disposed of in conventional waste disposal facility;

Unifrax, in Lorette, produces a fibrous insulator containing zircon.
 The waste arising from the manufacture of these fibres is regularly disposed of in a conventional waste disposal facility (56 m³).

Industrial	Management solution	Volume (m³)
C	VLLW	195
Cezus	LLW-LL	2,360
Comptoir des Minéraux et Matières Premières	waste storage facility	3
SNECMA	waste storage facility	11
Unifrax	waste storage facility	56

The industry for the production or use of compounds containing thorium

Certain industries handle thorium or its derivatives. The radionuclides may simply be totally or partially transferred to the residue, or concentrated by precipitation phenomena due to the industrial processes employed. Thorium improves the heat-resistance of alloys.

• The Messier foundry in Arudy manufactured objects based on thorium and magnesium alloys for the aeronautical industry. The waste generated by this production, declared in the Geographical Inventory (27 m³), is LLW-LL type and is stored on the Arudy site pending transfer to Cires for storage and pending the availability of an appropriate disposal facility;

The Arkema site located in Serquigny produced thorium nitrate from monazite and stores LLW-LL (around 1,780 m³) pending transfer to Cires for storage and the availability of an appropriate disposal facility.

Industrial	Management solution	Volume (m ³)
Fonderie Messier	LLW-LL	27
Arkéma	LLW-LL	1,778

5 The phosphates industry, particularly the manufacture of phosphoric acid and fertilizers

The industrial processes for the production of phosphate fertilizers lead to the production of solid waste (phosphogypsum) and contaminated scrap metal when certain parts of the installations are dismantled.

Grande Paroisse has several sites in Haute-Normandie (Anneville-Ambourville, Douvrin, Grand-Quevilly, Rouen, Saint-Étienne-du-Rouvray) on which very low-level waste is stored pending its transfer to a permanent disposal facility. The same applies to Yara France, which has a site at Rogerville. The characterisation of the 4,000 m³ of waste catalogued as VLLW in the 2012 edition has allowed it to be sent to a conventional waste disposal facility. Phosphogypsum is also disposed of on site. These sites are subject to regular surveillance.

As for the phosphogypsum originally dumped in heaps (more than 25 million tonnes), recycling plants processed this secondary raw material in the early 1980s to manufacture plasterboard for the building industry. A third of the solid waste (phosphogypsum) produced by the Grand-Quevilly plant was absorbed in this way.

Borealis Pec-Rhin in Ottmarsheim manufactures phosphoric acid and produces VLLW and LL-LLW. This waste is stored on the site.

Industrial	Management solution	Volume (m³)	
BOREALIS PEC-RHIN	VLLW	5	
DUREALIS PEC-RHIN	LLW-LL	21	
Grande Paroisse SA	VLLW	13	
Vere Free ee	VLLW	100	
Yara France	LLW-LL	120	

6 Water treatment facilities

Various processes are used to filter the underground water intended for consumption. The main processes are filtration using sand, activated charcoal, or resin.

The international bibliography on the topic mentions radon degassing at the facilities.

For example, the company Européenne d'Embouteillage in Donnery uses ion-exchanging resins to extract iron and manganese from water. These resins are likely to concentrate the radioactivity. Andra has asked this company about the possible presence of waste with high natural radioactivity levels on the Donnery site. This site declares no waste with high natural radioactivity.



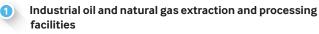
Coal-fired plants

Like water treatment facilities, the processes used in coal-fired plants produce radon by degassing. It is possible that the pipes, filters, or pumping equipment could concentrate the natural radioactivity of the water.

In the report drawn up by the ASN (2009), only exposure due to radon was evaluated, and no individual effective dose was adopted.

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 report by the Robin des Bois association as being producers of waste with high natural radioactivity.



Depending on the nature of the exploited terrain, the sand, silt or some tools may be contaminated by radioactive decay products of the natural uranium in the subsoil.

Total has exploited wells in Aquitaine, which leads to the production of waste with high natural radioactivity such as silt, scabs and sometimes gravel (approximately 1535 m³) contaminated with uranium. This waste is inventoried on several sites in the Geographical Inventory.

2 Geothermal applications

Concerning geothermal applications, radioactivity concentration effects seem to be largely the same as in gas and petroleum extraction cases; the natural radioactivity becomes concentrated in the pipes (formation of scabs) or in the filtration systems.

Other sectors would be likely to produce waste with high natural radioactivity, such as the paper industry and biomass combustion. However, pending additional investigations, this waste is not currently taken into consideration in the national inventory. These two industries are briefly presented below.

The paper industry 3

The paper sector, identified in the study by the Robin des Bois association, may also be responsible for the production of waste with high natural radioactivity according to the manufacturing processes used. For example, the use of a chlorine-free bleaching process leads to the precipitation of barium sulphate and radium sulphate in the pipes and in the filter used. The dose rates measured on contact can reach values of 4.5 μ Sv/h, which could lead to these industries not being made exempt.

4

Biomass combustion

In France in the 1990s, the combustion of biomass, particularly the use of wood as a fuel, increased.

The wood comes from forestry, sawmills, or scrap wood. Like the ash from coal-fired plants (see above), the ash from these steam supply systems concentrates the radioactivity not only from natural radionuclides but also potentially artificial radionuclides due to the fallout from the Chernobyl accident or nuclear tests (strontium-90 or caesium-137).

3. RECOVERED RESIDUE FROM PROCESSES

In addition to the industrial activities described in Section 2, other sectors listed in Appendix 1 of the order of 25 May 2005 produce recoverable residue from processes.

Thorium extraction installations

The Solvay plant at La Rochelle uses ore-based raw materials that were treated to lower their radioactivity level prior to being imported into France. The use of such raw materials produces suspended particulate matter (SPM), which the company considers to be materials with very low level radioactivity, which are recoverable thanks to their residual rare earth element content (see Chapter 2).

The Solvay plant at La Rochelle also produced raw thorium hydroxides up until 1987 (see page 39), in connection with the processing of monazite ore, which was permanently halted in 1994. The company considers these hydroxides to be materials, not waste. The thorium is considered to be recoverable because it can be used in a variety of industrial applications, most notably the medical sector, and in the nuclear sector in the longer term. Solvay is currently studying the reprocessing of raw thorium hydroxides. The quantity of LLW-LL that will result from this is thought to be around 11,000 m³.

Industrial coal combustion plants

Ashes are a natural byproduct of the combustion of coal in power plants.

The coal contains a few natural radioactive substances (uranium, thorium, and their daughter products), which are present in very low quantities and concentrated in the ash after the coal has burnt. When this coal is burnt to produce electricity, 99% of the dust is captured.

Fly ash recovered in this was is most notably used in the formulation of high added value concrete.

This addition allows the core temperature of concretes to be lowered during setting, which limits cracking on the one hand, and gives them good mechanical properties on the other hand.

EDF and E.ON (formerly SNET, created by the legal unbundling of the Charbonnages de France power plants in 1995) produce this type of ash and dispose of it on site in the form of a waste heap.

E.ON and EDF have decided to sell it.

With a view to recovering this ash and to comply with the ministerial order of 25 May 2005, EDF has carried out two studies with a view to measuring the exposure of workers and the population.

These studies applied pessimistic assumptions and the results concluded that workers are exposed to the order of 0.14 mSv/year, and the population to $2 \mu Sv/year$ for transfer via air, and less than $0.001 \,\mu$ Sv/year for transfer via water.

For the period 2000-2009 and counting all the activities of EDF and E.ON, the total production of carbon ash is1400 kilotons on average, and sales are around 1800 kilotons. The extra 400 kilotons sold compared to the quantity produced comes from destocking the waste heaps.

The average breakdown of these sales according to sectors of use is as follows:

- ready-made and prefabricated concretes: 44%,
- cements and hydraulic binders: 25%,
- roadworks: 16%,
- injection work: 4%,
- backfill: 8%.
- miscellaneous: 3%.

Total EDF and E.ON ash stock is currently 15 million tonnes divided among the sites named in the inset below.

Only one E.ON site has a stock of non-recoverable ash. It is listed in the Geographical Inventory: Fuveau.



EDF Sites

- Atton Blénod-lès-Pont-à-Mousson
- Richemont
- Woippy
- Loire-sur-Rhône
- Allennes-les-Marais
- Bouchain
- Champagne-sur-Oise
- Cordemais
- Saint-Leu-d'Esserent
- Nantes
- Beautor

E.ON Sites

- Hornaing
- Saint-Avold



Coal-fired power plant at Blénod lès Pont-à-Mousson

Other sites identified in the Robin des Bois Association's report of 2009 are not mentioned in the table below because the ash has been destocked and the land has been covered in topsoil.

In addition to the sites already mentioned, there are 24 others where coal ash is stored. These sites are essentially orphan sites, not declared by any operator. These sites will be presented in the next edition of the National Inventory.

Coal-fired power plants generate coal ash. This production consists of 90% fly ash and 10% furnace bottom ash. Their recovery channels are as follows:

Recovery	Type of centre	Use
Cements and concretes	Fly ash	 Moist fly ash: added to the raw feed Dry fly ash: added directly to the cement or concrete, up to 20% content. 80% of fly ash produced is certified according to the EN450* standard.
Road techniques	Furnace bottom ash	Backfill, platforms, road sub-layers. <i>A few notable examples:</i> high-speed railway lines, Metz-Nancy airport, Port 2000 in the Havre.
Others	Fly ash and furnace bottom ash	 Binder consisting of cement (approximately 10%) and fly ash to fill cavities, for example in Till and the stadium (Grand Stade) in Lille. Slurry for trenches: this mode is used to dig narrower trenches and close them again more quickly in cities.

*The EN 450 standard defines the physical-chemical characteristics and the quality control procedures for fly ash to be added to concrete, mortar, or slurry.

4. **STOCK OF** WASTE WITH HIGH NATURAL RADIOACTIVITY AT THE END OF 2013

At the end of 2013, the stock of waste with high natural radioactivity to be handled by Andra centres was around 21, 000 m³ of LLW-LL waste and 2100 m³ of VLLW.

Other waste of this type is disposed of in historic disposal facilities: these facilities (apart from those for coal ash) are presented in *Chapter 4.*

SWASTE WITH HIGH NATURAL RADIOACTIVITY THAT IS TO BE MANAGED BY ANDRA.

Category	Quantity
LLW-LL	21,000
VLLW	2,100
Total	23,100

REPORT 6

FOREIGN INVENTORIES OF RADIOACTIVE WASTE

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1. PURPOSE OF WASTE INVENTORIES

The management of radioactive waste begins with a knowledge of its types, respective quantities and characteristics. In a large number of countries with nuclear installations, the participants have drawn up a precise evaluation of the radioactive waste and spent fuel that they produce. This constitutes quantified and regular monitoring at every phase: processing, transport, storage and disposal. This monitoring can serve several purposes:

• to define a radioactive waste management programme, plan the required facilities and the R&D programmes intended to provide a means of dealing with waste that has no available solution;

• to organise traceability (for operational and forecasting purposes) in order to coordinate the flow of waste from production until storage or disposal;

• to ensure that the data concerning storage and disposal of waste is protected in accordance with the quality management requirements and is appropriate to the needs of future generations (Retrieval, Restoration and Maintenance of Old Radioactive Waste Inventory Records - IAEA-TECDOC-1548);

• to draw up an inventory of all spent fuels and radioactive waste produced, as well as a forecast of the quantities to come, including those resulting from dismantling. This inventory indicates the location and quantity of radioactive waste and spent fuel, in accordance with the appropriate classification of radioactive waste according to Council Directive 2011/70/Euratom of 19 July 2011.

Through these inventories, countries report on the volumes of radioactive waste produced and their situations (for example, if disposal systems exist). They also provide information on the location, radioactivity, packaging, origins, destination, etc. of the waste. These are published regularly, particularly by the signatories of the IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. According to the report from the U.S. General Accounting Office (GAO)¹ drawn up in 2007[1]: 18 countries (including France, Japan, Germany, Canada, etc.) create, based on national databases of radioactive waste inventories:

 the inventory of all radioactive waste by type, volume, location, and producer,

• the inventory of the status and use of the sealed radiological sources being held.

These countries have appointed a national authority to manage the inventory databases in order to:

verify the exhaustiveness and accuracy of these databases;

 demand that waste producers submit waste inventory information to the national authority at least once a year;

 draw up, based on inventory data, forecasts of the volumes of waste to be produced, and to be able to inform the public concerning the volume of waste to be stored in the short and long term.

For its part, the European Commission undertook an evaluation of its member countries in this regard, which was published in 2009[II]. This evaluation gave an overview of the national monitoring systems for data concerning waste implemented by the member states of the European Union. It gave recommendations for future waste management systems. The study covered the collection, publication, and management of data on radioactive waste and spent fuel in the states of the European Union and the candidate countries listed in the following table.

¹ Auditing, evaluation and investigation unit of the United State Congress in charge of monitoring public accounts.

[[]I] GAO-07-221 LLRW Foreign Radwaste Management Experiences.

[[]II] "Radioactive Waste and Spent Fuel Data Collection, Reporting, Record Keeping and Knowledge Transfer by EU Member States Final Report BS-Project N°. 0707-03 Contract No. TREN/07/NUCL/S07.78807."

C TYPE OF DATABASE FOR THE NATIONAL INVENTORY OF RADIOACTIVE MATERIALS AND WASTE

Answer	Country		
Centralised computer database with electronic data submission	Germany, Belgium, Croatia, Spain, Estonia, Finland, Hungary, Italy, Latvia, Macedonia, Netherlands, Romania, Slovenia, United Kingdom		
Computer database located at the nuclear power plant	Lithuania		
Centralised computer database with data submission via network	France ² , Czech Republic		
Centralised computer database with data collection via paper forms	Bulgaria, Slovakia		
Centralised paper archive data collection via paper forms	Greece		
Not specified	Austria, Cyprus, Denmark, Ireland, Luxembourg, Malta, Poland, Sweden, Turkey		

EU source: BS-Project No. 0707-03 Contract No. TREN/07/NUCL/S07.78807

All of these countries have regulatory specifications concerning the maintenance of a collection system for national data on waste and spent fuel.

The allocation of responsibilities for keeping an inventory is generally specified in the regulatory framework.

The national data collection system is organised in different ways according to the scale of the state's nuclear programme and the waste management system set up.

The following table shows the objectives of the countries to create inventory databases for their radioactive waste. It shows that the management of the facility capacities (disposal volume available) constitutes one of the main concerns.

	Political decisions	Keeping the public informed	Management plan	Safety	Financial management	Technical management		
Germany	Х	Х	Х		Х			
Austria			Х	Х	Х	Х		
Belgium	Х	Х	Х			Х		
Bulgaria		Х	Х	Х	Х	Х		
Croatia	Х	Х	Х	Х	Х	Х		
Cyprus	Information not received							
Denmark		Х	Х	Х		Х		
Spain	Х		Х	Х	Х	Х		
Estonia	Х		Х					
Finland	"The main objectives of the database are: I) to support the regulations concerning waste and the associated inspections; II) to provide a regular status report to the ministries; III) to inform the public."							
France	Х	Х	Х					
Greece			Information not received					

COUNTRY OBJECTIVES FOR THE CREATION OF INVENTORY DATABASES

	Political decisions	Keeping the public informed	Management plan	Safety	Financial management	Technical management	
Hungary	Х	Х	Х	Х	Х	Х	
Ireland							
Italy		Х	Х				
Latvia	Х	Х	Х	Х	Х	Х	
Lithuania			Х			Х	
Luxembourg						Х	
Macedonia		Х	Х	Х	Х	Х	
Malta	Information not received						
Netherlands	Information not received						
Poland	Information not received						
Portugal	Information not received						
Czech Republic	Х	Х	Х	Х	Х	Х	
Romania		Х	Х		Х	Х	
Slovakia		Х	Х		Х	Х	
Slovenia	Х	Х	Х	Х	Х	Х	
Sweden	Information not received						
Turkey			Information not	received			
United Kingdom	Х	Х	Х			Х	

EU source: BS-Project No. 0707-03 Contract No. TREN/07/NUCL/S07.78807

The inventory work within the European Commission was specified by the 2011 Directive described below.

2. EUROPEAN DIRECTIVES

CONCERNING THE MANAGEMENT OF SPENT FUEL AND RADIOACTIVE WASTE (2011/70/EURATOM)

In 2011, the EU Council adopted Directive 2011/70/Euratom, which establishes a community framework for the management of spent fuel and radioactive waste, from production to disposal.

It thus supplements Euratom's legislative instruments, which do not yet deal with this subject.

It places responsibility in the hands of the member states and producers for the responsible and safe management of spent fuel and radioactive waste, and for the protection of persons and the environment from the dangers of ionising radiation. It requires the states to equip themselves with a legal framework for nuclear safety, with:

• a competent safety and monitoring authority, independent of the waste producers;

 authorisation holders capable of demonstrating and maintaining the safety of their facilities in terms of the management of spent fuel and radioactive waste throughout their life.

It also obliges the States to draw up a national programme to create and implement the policy for the management of spent fuel and radioactive waste, including:

• general targets that the national policies of the member states must reach in terms of the management of spent fuel and radioactive waste;

 important deadlines in view of the targets to be reached for the national programmes;

 an inventory of all spent fuels and radioactive waste, and the estimates of future quantities, including those resulting from dismantling operations. This inventory must clearly indicate the location and quantity of the radioactive waste and spent fuel in accordance with the appropriate radioactive waste classification.

Moreover, the member states must:

 provide the necessary financial resources for the management of spent fuel and radioactive waste;

- maintain adequate human resources;
- ensure the transparency of information and public participation;

 re-examine and regularly update their national programme to take developments and progress into account and to ensure that peer reviews are carried out;

• favour the disposal of radioactive waste in the state that produced it. However, the directive gives member states the possibility of storing

their radioactive waste in another country (member state or, under certain conditions, a third-party state).

This directive came into force on 23 August 2011 and the member states had two years to transpose it into national law.

As one of its expectations, the directive notes that geological disposal is the benchmark solution for intermediate-level and high-level longlived waste. In most countries, geological disposal has been imposed as the long-term solution, following many studies examining various options.

The member states shall submit a report to the Commission on the implementation of the directive as of 23 August 2015, and then once every three years, taking advantage of the evaluations and reports written under the terms of the Joint Convention.

The Commission shall submit the following to the European Parliament an the Council:

 a report on the progress made in the context of implementing the directive;

• an inventory of the spent fuel and radioactive waste present in the Community and forecasts for the future.

3. MONITORING CARRIED OUT BY THE INTERNATIONAL ATOMIC ENERGY AGENCY

The IAEA is a United Nations agency that makes an international database called NEWMDB available to the public. This database is primarily an inventory of radioactive waste in various member countries. All data is updated on a regular basis and presentation formats tend to be standardised from one country to another.

Each country, which generally has its own radioactive waste classification, can transpose it into that of the IAEA, stipulated in the general safety guide GSG-1 [III]. Converted according to a common classification in this way, each inventory can be uniformly integrated into the NEWMDB.

Moreover, the radioactive waste inventory volumes in each country can be drawn up in various ways: volumes of waste in raw, treated, packaged, stored, or ready-for-disposal forms. There is nevertheless a trend towards harmonising the volumes reported, which are increasingly those of the waste ready to be disposed of (volume as disposed). Every three years, member countries publish a national report under IAEA supervision, within the framework of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. The last conference took place in 2015 at IAEA headquarters in Vienna (Austria). A part of these reports is devoted to existing inventories of radioactive waste and spent fuel updated at the time of their publication.

National reports published by member states are accessible from the IAEA website. For the meeting for the fourth revision of the Joint Convention of the IAEA, the reports from the following countries were published: Germany, Argentina, Australia, Belgium, Brazil, Canada, Korea, Denmark, United Arab Emirates, Spain, Estonia, United States, Euratom, Russian Federation, Finland, France, Ireland, Japan, Lithuania, Norway, Czech Republic, United Kingdom, Slovakia, Slovenia, and Sweden.

4. **THE INVENTORY** IN CERTAIN COUNTRIES

UNITED KINGDOM

In the United Kingdom, a radioactive waste inventory is compiled every three years by the National Decommissioning Authority (NDA), in partnership with the Ministry for Climate Change.

The last edition in 2014 described the status of existing waste on 1st April 2013 and presents all the anticipated waste in the United Kingdom. It is directly accessible from a new dedicated website: http://www.nda.gov.uk/ukinventory/.

It includes information on the quantities, types, and characteristics of existing and future waste. Forecasts are based on assumptions regarding electricity production, decommissioning and choice of channel.

Except for the storage of short-lived, low- and intermediate-level waste, the facility near Drigg (not far from Sellafield), the LLRW Repository, no facility lists radioactive waste other than that produced by the facility itself. The 2013 inventory lists 1326 sites and waste channels that concern the activities of the nuclear industry, defence, and small producers. It counts the actual or forecast waste mainly located on the production site and not yet subject to final disposal.

The inventory lists 4,450,000 m³ of existing or future waste, already stored or to be produced by the installations being operated. This volume does not include the 900,000 m³ of waste already stored in the LLRW Repository, which is counted separately. The inventory data corresponds to the status of the waste when inventoried, i.e. volumes occupied in the reactor vessels (case of liquids to be treated), cells, silos, drums, etc. that contain them.

The overall expected volumes of waste, existing and forecast, are evaluated in the form of packaged waste.

The inventory is presented in several documents:

summary of the inventory;

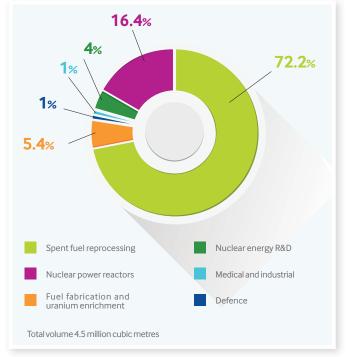
 summary of the data to be communicated internationally (IAEA and others);

scope and modalities of the inventory;

 scenario for forecasting the production of radioactive materials and waste,

quantity of waste according to origin;

BREAKDOWN OF RADIOACTIVE WASTE PRODUCED AND FORECAST IN THE UNITED KINGDOM, 2013



UK Radioactive Waste Inventory, NDA and DEC

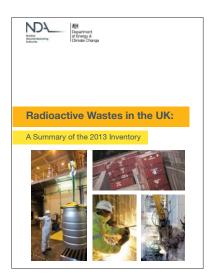
- composition of the radioactive waste;
- radioactive content of the waste;

 radioactive materials and waste not counted in the United Kingdom 2013 inventory.

The summary of the 2013 inventory is aimed at a wide audience. It gives the definition and describes the nature of the radioactive waste in the United Kingdom: how is it produced? How much of it is there? How is it managed?

The other various inventory reports provide detailed information concerning the characteristics: mass, volumes, radioactivity, conditioning and packaging of the waste listed. They give details of the existing and future waste, giving a comparison to the 2010 inventory.

The summary of the 2013 inventory intended for international publication on 1 April 2013 satisfies the needs for an inventory declaring radioactive waste to bodies such as the IAEA, the European Commission, and the NEA/OECD. It reviews the classification of both short-lived and long-lived waste in the United Kingdom.



SWITZERLAND

In a context of relatively modest nuclear activity, Switzerland, via Nagra (a co-operative company for the disposal of radioactive waste), compiled its first inventory of its waste in 1984. This publication, updated in 1994, 2008, and 2014, reflects the contents of the MIRAM database (Model Inventory of Radioactive Materials) drawn up to satisfy the needs of the bodies in charge of waste management.

The inventory lists all materials considered as waste according to the Swiss classification, and therefore does not include VLLW or recoverable materials. It consists of a main report supplemented with 162 standard data sheets, each corresponding to a type of waste.

It is drawn up according to a basic scenario forecasting, on the one hand, the operation of the existing nuclear power plants for 60 years, except the Mühleberg plant which is due to shut down in 2019, and on the other hand, a collection period for waste from the medical, industrial and research sectors, and extending until 2065.

The technical files contain information most notably on the type of waste (raw waste), its source, its packaging, the changes in its quantity, the inventory of radioactive materials and radionuclides, radiotoxicity, dose rate and heat rating, surface area to mass ratios, and the production of radiolysis gases.

The inventory provides a graphical representation of the volumes, inventories, and radiotoxicity of waste throughout the duration of its production and, for the radiological characteristics, over a period of up to one million years.

All these documents are available to the general public on the NAGRA website (www.nagra.ch). Periodic updates are planned in accordance with the progress of the disposal site selection procedure ("sectoral plan").



BELGIUM

Ondraf, the national radioactive waste organisation, is responsible for drawing up a two-part inventory: one part on the radioactive substances present on Belgian territory, and the other on "nuclear liabilities", which lists the various sites and producers of radioactive waste.

This task was assigned to it by the Royal Order of 16 October 1991, and was extended to all sites by the Act of 12 December 1997.

Ondraf continually updates a quantitative and qualitative inventory of all present and forecast radioactive waste, including unused fissile materials and future waste from the dismantling of nuclear installations.

The inventory is published every five years, and the last one, which came out in 2013, concerned the period 2008-2012.

It listed 685 sites with radioactive waste, radioactive materials obtained from dismantling, and nuclear materials.

It draws up a forecast of waste volumes according to a scenario that suggests that all existing nuclear installations are dismantled and produce no more waste. This timescale largely depends on the scenarios and management timetables considered: the spent fuel management scenario, the facility dismantling scenarios, the disposal calendars, etc. The inventory lists non-nuclear sites such as the one at Olen which contains radium-bearing waste from ore processing , and facilities where radioactive sources are kept.

The inventory compiled in Belgium is intended to verify the availability of the financial resources necessary for waste producers to take all of their waste into account. The idea is to prevent the waste from becoming a liability, i.e. a burden on the community if the resources were insufficient or absent.

The 2013 version places particular emphasis on the methodological aspects of evaluating financial resources and the associated provisions. Defined by Article 9 of the Planning Act of 12 December 1997, the nuclear liability task assigned to Ondraf (www.nirond.be) involves:

 "drawing up a directory of the location and status of all nuclear facilities and all sites containing radioactive substances, with a radioactive substance defined as "any substance containing one or more radionuclides whose activity or concentration cannot be disregarded as far as radiation protection is concerned"; estimating the associated decommissioning and cleanup costs;

 evaluating the availability and sufficiency of financial provisions for funding ongoing or future operations;

updating this inventory every five years."

The inventory is based on declarations submitted by the operators, who are responsible for all information transmitted to ONDRAF.

The final report is not made public, since it contains operator-specific financial data considered by certain operators as commercially sensitive.

A summary of the inventory is available on the ONDRAF website.

The fourth inventory report, covering the period 2013-2017, should be published in 2018 in the section concerning nuclear liabilities. It is preceded by an inventory of radioactive waste drawn up on the basis of information from the producers.

This inventory collects the physical, radiological, and chemical data concerning the waste.



GERMANY

Since 1984, the German Federal Office for Radiation Protection (BfS) has developed a systematic approach to collecting and updating the data in the radioactive waste inventory database. This data concerns the existing quantities and volumes as well as the forecasts for the next year, for each decade until 2080.

BfS conducted annual surveys with producers, by means of a questionnaire concerning the volumes of waste produced, treated and conditioned. This only concerned waste to be disposed of.

In Germany, waste likely to receive radiation protection clearance is not counted in the inventory. This is mainly depleted uranium and uranium and plutonium obtained from the processing used in the manufacture of fuel elements.

Recycled plutonium and uranium, however, are counted annually by the Ministry for the Environment, Nature Protection and Nuclear Safety (BMU). The present and future waste volumes are supplemented by chemical data stating the organic compositions of the waste and the hazardous non-organic substances in accordance with the protection of the subsoil water.

Today, forecasts for the production of radioactive waste are drawn up by the BfS according to a scenario modified by the 13th amendment of 6 August 2011 of the law on nuclear energy (atomic law).

With this amendment, which was added following the events that took place in Japan in 2011, leading to a re-examination of the risks related to the use of nuclear power, eight operating permits for nuclear power stations were not renewed.

The operating permits for the nine remaining reactors will expire between 2015 and 2022. The complete German National Radioactive Waste Inventory is not yet available to the public (not all aspects of its preparation are covered). It could constitute one of the sections of the future National Radioactive Waste Management Plan, where the future disposal site for exothermic waste remains to be defined.

On the other hand, from a legal and regulatory standpoint, the decree of 2001 concerning radiation protection contains provisions concerning radioactive waste taken in application of the standards set forth in the atomic law.

In accordance with that decree, the holder of a licence is obliged to provide advance, annual forecasts of the quantity of radioactive waste that will result from its activities, and to describe how they will be managed and stored. The holder must also draw up an inventory of radioactive waste in the forms specified in the appendix of that same decree.

Although it is not public, the inventory of radioactive waste and spent fuels in Germany is therefore drawn up regularly by the BfS. A presentation of it is nevertheless made once every three years via the Federal Republic of Germany's report in the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste. This national report was published in 2014 in preparation for the fifth IAEA conference on the Joint Convention, in May 2015.

Finally, in connection with the National Plan for the Management of Radioactive Waste drawn up consecutive to Directive 2011/70/ euratom, information and data on the quantities of radioactive waste and spent fuel are presented to the European Commission.



Konrad

SPAIN

ENRESA (Andra's Spanish counterpart) compiles and updates an inventory of radioactive waste produced in Spain, based on information supplied by waste producers. The first inventory studies were initiated in 1986, with the implementation of the 1st National Radioactive Waste Management Plan. Today, this information is compiled in a database used to produce a summary report.

Although the inventory is updated annually, its last publication dates from January 2006 and is based on data as of 31 December 2004. The inventory is mainly intended to supply the volumes of the waste produced and disposed of at each facility, as well as forecasts for the production of waste that will need to be handled in Spain. Inventory data is classified by waste producer type. It includes fuel assemblies, reactor waste and waste at the El Cabril disposal facility. It indicates volumes of waste already produced and to be produced, as well as waste produced in Spain but due to be treated and stored abroad. Waste from former mining facilities is also included in the inventory.

Royal decree 102/2014 concerning the responsibility and safety of spent fuels and radioactive waste regulates the activities and funding of Enresa. This public body is responsible for drawing up an inventory of the radioactive waste stored and disposed of, as well as waste from dismantled or closed installations. In application of this decree, the National Radioactive Waste Management Plan (National Programme of the Waste Directive) includes an inventory of spent fuels and radioactive waste produced and to be produced, giving a precise indication of their quantities and locations according to a classification based on their final destination.

The contract between the waste producers and Enresa obliges producers to supply an initial inventory presenting the current situation at the time of signing the contract according to type and quantity of radioactive waste. In addition, the producer must indicate the following information each year: • five-year forecasts of operational radioactive waste to be produced, classified according to family;

- ten-year forecasts of fuels,
- five-year forecasts of special and particular radioactive wastes,

• inventory of waste produced in the previous year, by family (operational, spent fuel, and special and particular waste),

• the timetable of upcoming facility closures.

A national database of radioactive waste and spent fuel 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 published directly and publicly by Enresa. It is however described via the NEWMDB of the IAEA, and by the Spanish national report published at the fourth conference on the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste organised by the IAEA.



El Cabril

UNITED STATES

Several systems for the inventory and tracking of radioactive waste exist in the USA. They differ according to which body is in charge of regulating them:

• the Department of Energy (DOE) for the defence sector, under the aegis of the federal government,

The Nuclear Regulatory Commission (NRC) for the commercial sector.

Disposal sites are often determined by the origin and nature of the waste.

The NRC draws up national inventories of spent fuel from the commercial sector and sealed sources.

For other categories of waste, there is no national inventory system that uniformly collects all the information from every facility and body, whether a producer, broker, processor, or disposal manager.

However, the waste producers in the commercial nuclear sector use a Manifest Information Management System to generate manifests when shipping waste to intermediaries. Radioactive waste is disposed of by both the DOE and private organisations. The disposal sites will ultimately be placed under the responsibility of the Federal or State governments. Spent fuels and high-level waste is currently stored.

Waste from several producers can thus be grouped before treatment and disposal. The operators of disposal facilities store the data throughout the lifetime of the facilities and arrange for it to be archived after closure.

The specifications of the inventories are defined by the laws of the states in which the disposal facilities are located, or the federal government.

The inventory must include a paper record of all waste, from the time it is produced and for as long as it remains at the disposal facility.

The NRC requires that waste producers in the private sector implement specific inventory systems for all waste at disposal sites.

For the defence sector, the DOE (www.em.doe.gov) also has its own specific inventory systems implemented on the sites and illustrated by the following examples:

 Solid Waste Information Tracking System (SWITS), used for solid waste, LILW and transuranic waste stored at the Hanford site

 Integrated Waste Tracking System (IWTS), implemented in the Idaho National Laboratory; • Waste Isolation Pilot Plant (WIPP) Waste Information System (WWIS) which constitutes the inventory (transuranic waste) of the first geological disposal site in operation.

American inventories are often very complete, covering all the production that generates radioactive waste: mining waste, site cleanup activities, and so-called mixed low-level waste, containing both radioactivity and toxic chemical residue.

The information is generally freely accessible in the form of databases on the Internet, particularly the WIPP database used by the DOE.

In addition, the DOE prepares a summary of inventory data on nuclear facilities. This summary is published in the national report submitted to the International Atomic Energy Agency (IAEA) in accordance with the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. It is also updated in the database of the NEWMDB inventory operated by the IAEA.

The American inventory published in this national report on the safety of spent fuel and radioactive waste lists the waste according to the DOE and NRC classifications. It includes mining residue and materials:

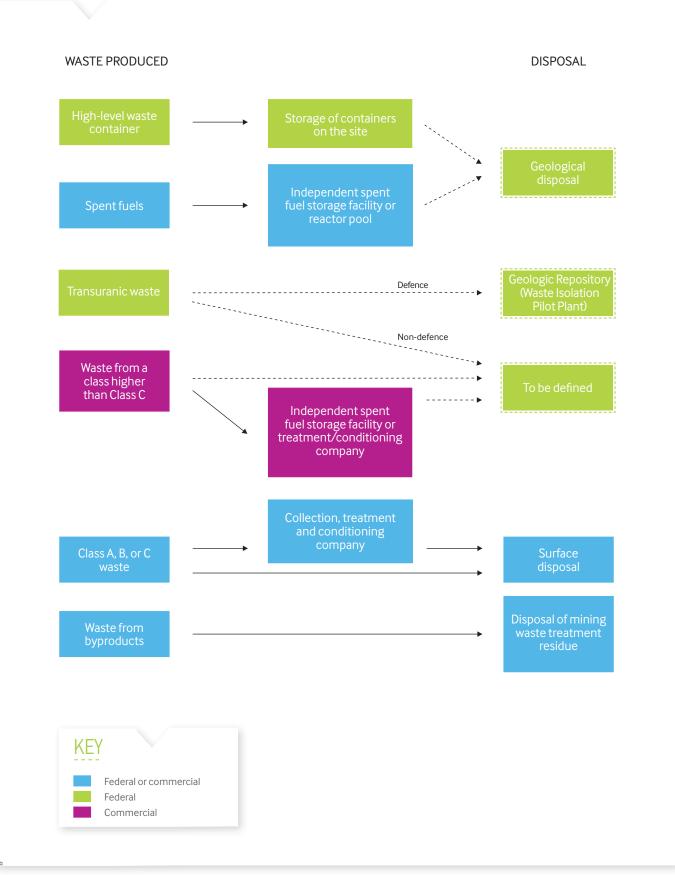
 the provisional inventory of spent fuel is updated annually. Spend fuel is not currently sent for disposal, but stored at the producers' facilities.

• The inventory of radioactive waste disposed of is published in summary and detailed form by sector (DOE or NRC). Waste stored on the production sites is not listed in this inventory. It is covered in an operational and flow tracking inventory drawn up by the operators.



Waste Isolation Pilot Plant.





Source: D. Tonkay, DOE, Waste Inventory Records Keeping Systems United States of America, August 2005

SUMMARY TABLE OF INVENTORIES OF RADIOACTIVE WASTE DISPOSED OF ACCORDING TO SECTOR AND INSTALLATION (US 5TH NATIONAL REPORT FOR THE JOINT CONVENTION IAEA, SEPT. 2014)

Sector	Facility type	Waste type	Number	Inventory	Units
	Geological disposal (WIPP)	TRU	1	9.10x10⁴	m ³
Government	"Greater Confinement Disposal (boreholes)" at the Nevada National Security Site	TRU	1	2.00x10 ²	m³
	Surface Disposal	LLW	18	1.51x10 ⁷	m ³
				1.25x10 ²	Reactor compart- ments
	Operating Surface Disposal	LLW (Class A, B, C)	4	4.63x10 ⁶	m³
Commercial		AEA Section 11e.(2)	1	1.40x10 ⁶	m³
	Closed Surface Disposal	LLW	4	4.38x10⁵	m ³
Government/ Commercial	Title I UMTRCA Disposal	Residual Radioactive Material (tailings)	22	2.45x10 ⁸	tonnes
Commercial	Title II UMTRCA Disposal	AEA Section 11e.(2)	44		
Government	Other disposal cells, after closure (Weldon Spring Site and Monticello)	Residual Radioactive Material (tailings)	2	3.03x10 ⁶	m ³

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CANADA

Canada publishes a three-yearly inventory specifying the location of radioactive waste and draws up a status report on production and the quantities accumulated. It also provides forecast waste production quantities until the end of life of the current reactor fleet, planned for 2050.

The data for the inventory of radioactive waste comes from several sources, especially the Nuclear Waste Management Organisation (NWMO) in charge of making the inventory of spent fuels.

The data comes from regulatory documents, reports, and bulletins supplied by the regulatory body, waste producers, and waste management facilities. Regulatory documents include: annual or quarterly compliance reports, annual safety inspections, and decommissioning reports submitted to the safety authority (CCSN).

Finally, every licence holder must create and implement an accounting system that covers radioactive waste and spent fuels. This system and the resulting records are subject to regulatory monitoring.

Radioactive waste is presented 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 ore extraction and uranium concentration.

The first category concerns the fuel clusters of CANDU-type reactors. The second category is divided into common waste resulting from the operation and dismantling of facilities and legacy waste resulting from past activities (e.g. Port Hope radium refinery). Finally, Canada lists the uranium processing waste in currently operating, inactive or decommissioned sites.

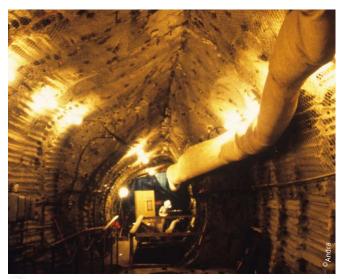
The inventory is compiled by the Low-Level Radioactive Waste Management Office. This body is also responsible for current and legacy waste management programmes. The Office is administered by Atomic Energy of Canada Limited (AECL) on behalf of the Ministry of Natural Resources. Four inventories were published between 2009 and 2012:

HISTORY

Canada has been producing radioactive waste since the early 1930s, at which time the first uranium mine began its operations in Port Radium, Northwest Territories. Radium was refined for medical purposes, and later, uranium was processed in Port Hope, Ontario.

The research and development activities concerning the use of nuclear energy in electricity production began in the 1940s at the Chalk River Laboratories (CRL) of Atomic Energy Canada Limited (AECL).

Today, the radioactive waste generated in Canada comes from mines and uranium concentration plants, uranium refineries and uranium conversion plants, nuclear fuel manufacture, the operation of nuclear reactors for the purpose of generating electricity, nuclear research, and the production and use of radio-isotopes.



Pinawa underground laboratory

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CHAPTER 6

APPENDICES & GLOSSARY

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APPENDIX 1

Essentials

METHODOLOGY USED FOR THE NATIONAL INVENTORY

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2. Documents providing data Synthesis Report Geographical Inventory Catalogue of Families Focus-on 2015	162





1. PROCEDURES USED TO PREPARE THE NATIONAL INVENTORY

REGULATIONS

Article L. 542-12 of the French Environmental Code assigns Andra the task of "establishing, updating every three years and publishing the inventory of radioactive materials and waste found in France, as well as its location".

The Council of State Decree of 29 August 2008 [I] which implements Article 22 of the Act of 28 June 2006 and the Ministerial Order of 9 October 2008 [II] modified by the Ministerial Order of 4 April 2014 [III] define the obligations of those producing and possessing radioactive materials and waste regarding declarations.

For the 2015 edition of the *National Inventory*, the existing waste stocks are as of the end of 2013, forecasts are as of the end of 2020, end of 2030 and the end of the projected operating life for each facility.

Article 22 of Act 2006-739 of 28

June 2006 codified in the French

Environmental Code [1V]

Q

29 AUGUST 2008

Decree 2008-875 [I]

Q

Order [II]

ARTICLE VIII OF THE ORDER OF 4 APRIL 2014[III] SETS THE REFERENCE DATES FOR THIS AND FUTURE EDITIONS

Edition	Stock date	Foreca	st dates
2015	31/12/2013	End of 2020	End of 2030
2018	31/12/2016	End of 2030	End of 2040
2021	31/12/2019	End of 2030	End of 2040
2024	31/12/2022	End of 2030	End of 2040
2027	31/12/2025	End of 2040	End of 2050
2030	31/12/2028	End of 2040	End of 2050



Only waste that corresponds to the operation and dismantling of facilities that exist or authorised as of the end of 2013 are evaluated in the National Inventory.

Decree 2008-875 of 29 August 2008 which implements Article 22 of the Planning Act of 28 June 2006 on the sustainable management of radioactive materials and waste.
 Order of 9 October 2008 on the type of information that those responsible for nuclear activities and the companies identified under Article L.1333-10 of the French Public Health Code are obliged to collate, update and periodically submit to Andra.

[[]III] Order of 4 April 2014 (modifying the Order of 9 October 2008) on the type of information that those responsible for nuclear activities and the companies identified under Article L.1333-10 of the French Public Health Code are obliged to collate, update and periodically submit to Andra.

W Planning Act 2006-739 of 28 June 2006 relating to sustainable management of radioactive materials and waste.

PRINCIPLES

Compilation of the National Inventory of Radioactive Materials and Waste is based on strict methodology and meticulous data verification procedures.

It has three aims:

• inventory radioactive materials and waste held by each producer or other entities in France, including waste from other countries that will be returned to foreign customers. Andra has performed this survey since 1992. Originally based on voluntary declarations by those producing and possessing waste, this task now falls under the recent regulatory framework described above;

 prepare an overall view of current and future radioactive materials and waste in accordance with forecast scenarios with snapshots of stock as of key dates defined by ministerial order as well as at the end of facility life;

 outline major trends in the production of radioactive materials and waste at the end of facility life according to diverse planning scenarios.

SCENARIOS

Forecast scenario

Any operator of a site consisting of one or more basic nuclear installations, one or more secret basic nuclear installations or one or more installations classified on environmental protection grounds using radioactive materials[I] is obligated to submit data on baseline quantities of radioactive materials and waste every three years. This data is based on the industrial and commercial operation scenario for their facilities.

Planning scenario

Planning scenarios, defined by the steering committee for the National Inventory, are based on intentionally diverse assumptions of nuclear energy policy. They are used to estimate the quantities of waste that would result from implementing these scenarios, which do not preempt possible evolutions in France's energy policy.

RADIOACTIVE MATERIALS AND WASTE IN FRANCE.

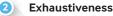
The National Inventory accounts for all radioactive materials and waste found in France. It thus takes into account radioactive materials and waste resulting from the processing of fuels from abroad, even though they will be returned to the countries of origin. Operators of nuclear facilities perform reprocessing operations of behalf of customers in other countries publish an annual report that lists all radioactive materials and waste that belong to customers in other countries in compliance with Article L. 542-2-1 of the Environmental Code.

Five principles have guided the preparation of the National Inventory to ensure its reliability, quality and suitability 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 authorities prepare the National Radioactive Materials and Waste Management Plan by providing them with a realistic inventory that reflects the waste producers' best estimates at the time of the declarations.



The National Inventory provides a survey not only of existing waste resulting from recent and current activities, but also of that produced since the earliest applications of the properties of radioactivity for industrial, military and medical purposes. The aim is to present a "snapshot" of all waste found in France at a given time regardless of its physical or chemical state, conditioning, liquid or solid, and high of low level of activity. The scope of the inventory is not restricted to waste disposal or storage facilities. It also covers all polluted sites as well as facilities that contain waste - even temporarily - awaiting collection by Andra, e.g., medical research and university laboratories. It also includes radioactive materials.

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

3 Neutrality

The National Inventory transcribes the collected data in a factual manner without pronouncing judgement on the potentially hazardous nature of the products described.

Transparency

The National Inventory provides an overview of radioactive materials and waste, regardless of source. This approach seeks to complement the efforts to increase transparency in recent years undertaken by public authorities, waste producers and the French Nuclear Safety Authority (ASN) [V].

To ensure transparency, a steering committee chaired by Andra's chief executive officer and composed of members from outside Andra oversees preparation of the National Inventory.

Responsibility of declarants and validation of management solutions by Andra

The National Inventory provides the data given in the declarations submitted by waste producers. Each producer is therefore responsible for the declaration it submits. Although Andra has no policing powers, the regulatory provisions of the Act of 28 June 2006 entitle it, if necessary, to inform the appropriate authorities should those producing or possessing waste fail to fulfil their obligations regarding declarations. Furthermore, under Article 2 of Decree 2013-1304 of 27 December 2013 setting requirements for the National Radioactive Materials and Waste Management Plan, Andra verifies whether the waste management solution proposed by the producer is suitable. The obligations of waste producers regarding declarations do not release Andra from its duty to ensure that the inventory is exhaustive by cross-checking various sources of information, including scrutiny of national and local media. When the presence of radioactive waste has been proven on sites that are not yet listed, the sites in question are incorporated into the National Inventory at the next update.

ENTITIES

Since 2008, those producing or in possession of waste can make declarations by using the Internet. The procedures for verifying declared data depend on the type of producer:

 major entities in the nuclear industry (Andra, AREVA, CEA, EDF) that manage several sites.

Each site appoints "officers" who are well-acquainted with stocks and complete the declaration forms (declarants). The declarations are then verified and validated by a supervisor from the headquarters of each organisation (declaring supervisor). The forecasts are declared directly by supervisors;

• "small-scale nuclear activities waste producers" produce less radioactive waste. Each nuclear activity manager submits a declaration directly without supervisor validation.

DEFINITION: "SMALL-SCALE NUCLEAR ACTIVITIES WASTE PRODUCER"

"Small-scale nuclear activities waste producers" are those producing or in possession of radioactive waste from the medical sector, research (excluding CEA) and industry except for nuclear power. It primarily concerns producers that fall under Article R.542-68 of Decree 2008-875 of 29 August 2008 [I]. Andra verifies all data in the declaration (comparing it with the previous declaration, checking for consistency, cross-checking with any other available sources and examining the proposed waste management solution).

If the declarations need to be corrected in any way, Andra contacts the producer, then validates the corrected data.

The steering committee for the National Inventory was created with concern for transparency and effectiveness. It offers the opportunity to develop a consensus on the inventory. The steering committee's main mission is to validate the assumptions needed for performing the National Inventory and the main conclusions resulting from the analysis of the declarations before they are made public. It must also ensure that the data is made available to the public with the greatest possible transparency.

In addition, in compliance with the requirements of the 2013-2015 National Radioactive Materials and Waste Management Plan (PNGMDR), each year Andra presents the plan's working group with an update on the quantities of waste in disposal or storage facilities based on producers' annual declarations.

[] Decree 2008-875 of 29 August 2008 which implements Article 22 of Planning Act 2006-739 of 28 June 2006 on the sustainable management of radioactive materials and waste.

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

..... NATIONAL INVENTORY STEERING COMMITTEE

The committee validates the consistency of all volumes of existing and future waste presented in the National Inventory and the assumptions retained for planning scenarios. The committee also defines conditions for the data given in the National Inventory. The committee comprises:

- representatives of relevant ministries (environment and energy);
- a representative of the French Nuclear Safety Authority (ASN);
- representatives of the main waste producers (from the nuclear power sector as well as others);
- a representative of the Parliamentary Office for the Evaluation of Scientific and Technology Choices (OPECST) with observer status;
- a representative of the National Assessment Board (CNE) with observer status;
- representatives of civil society and environmental protection organisations as well as local information commissions (CLI);
- a representative of the French High Committee for Transparency and Information on Nuclear Safety (HCTISN).

2. **DOCUMENTS** PROVIDING DATA

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

- the present Synthesis Report;
- Geographical inventory;
- Catalogue of Families;
- Focus-on 2015;
- Essentials.

All of these documents are available in multimedia format on Andra's website: www.inventaire.andra.fr.

The management solution proposed in the National Inventory does not ensure the waste will be accepted at the corresponding waste disposal facility.

The National Inventory presents all waste, whether or not it has already been conditioned; assumptions about conditioning methods must also be made to quantify waste volumes.

.....

FIVE DOCUMENTS



SYNTHESIS REPORT

This document provides a detailed description of all current and future radioactive materials and waste found in France; Quantities are grouped by category and economic sector.

The quantitative section is supplemented by special reports which focus on specific subjects such as waste treatment and conditioning or dismantling and remediation of facilities.



GEOGRAPHICAL INVENTORY

The Geographical Inventory reproduces the declarations of producers. It presents each site by administrative region, department and municipality, classifying it by the economic sector of those producing or in possession of the waste. It also inventories Andra's repositories, national defence facilities, small-scale nuclear activities waste producers and legacy sites, which cover mining, legacy disposal sites and proven polluted sites including those related to the use of radium.

The data is transferred, in a factual manner, for each region in summary tables for "small-scale nuclear activities waste producers" and defence facilities other than secret basic nuclear installations and experimental facilities and sites, and in geographical reports for other declarants. The tables and reports provide data on radionuclides used and the waste volume (when available); the management solutions are noted. Depending on its importance, a site may have one or more geographical sheets. The most detailed geographical reports provide the inventories of the largest producers such as AREVA, CEA and EDF.

The waste category as defined in *Chapter 1* is given, in addition to the waste family to which it belongs (described in the Catalogue of Families). Each type of waste found on the site is noted, along with its activity and the volume of waste after conditioning.



CATALOGUE OF FAMILIES

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 presentation, the waste has been assigned to "families". A detailed description of each waste family in the National Inventory can be found in the Catalogue of Families of radioactive waste.

A family is defined as a type of waste having similar characteristics.

The volumes of waste in the Catalogue of Families are given in "m3 as disposed". This unit has been adopted for the statements. It allows the waste to be accounted for using a single, common unit. The forecasts also use this unit.

Total activity of waste is calculated by Andra using the inventory date (31 December 2013 of the preceding year) in becquerels while specific activity in becquerel per gramme of package is generally indicated as of the date the package is produced.

In the 2015 edition, the Catalogue of Families provides for each family report, the waste stocks as of the end of 2013, whether in repositories or storage, as well as forecasts for production as of the end 2020 and the end of 2030. The quantities are expressed in volumes as disposed.

The forecasts are based on industry scenarios. For the nuclear energy sector, the scenario adopted for the 2015 edition of the National Inventory is a scenario in which nuclear energy production continues with the nuclear power plants operating for 50 years.



FOCUS-ON 2015

Focus-on 2015, the version of the National Inventory prepared for the general public.

This document defines the concept of radioactive materials and waste, provides a statement of existing and forecast quantities and an overview of the current or planned management solution.



ESSENTIALS

Essentials 2015 provides the overall figures for the National Inventory 2015 and is used to update the National Radioactive Materials and Waste Management Plan (PNGMDR) every three years.

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IS THE NATIONAL INVENTORY REALLY EXHAUSTIVE?

Successive updates of surveys since 1993 have brought fuller and more detailed knowledge concerning the location of waste and some of its characteristics, as the producers themselves come to learn more about their waste products.

The issue of exhaustiveness arises at two levels: the location of sites where radioactive waste is present, and the quantities and category of the waste described at surveyed sites.

A producer may overlook some waste when making a declaration. As the major producers also declare their waste stocks to the French Nuclear Safety Authority (ASN), there is little risk that anything will be omitted. The two declarations are generally compared by the producer or made jointly. In addition, the French Nuclear Safety Authority (ASN) carries out regular on-site checks of declarations.

In the case of AREVA, waste stocks are also audited by a body authorised by its customers.

From one edition to the next, some facilities may no longer be included in the survey because they no longer contain radioactive waste (e.g. dismantled and remediated facilities). Conversely, there may be new waste-producing facilities.

Since 2008, declarations have been obligatory, making the data declared for the National Inventory more exhaustive. Furthermore, in response to incidents at the Tricastin site in southeast France in the summer of 2008, the Ministry of Ecology, Energy, Sustainable Development and Town and Country Planning asked the High Committee for Transparency and Information on Nuclear Safety (HCTISN) for recommendations. As a result, more detailed information concerning certain legacy sites has been provided in the National Inventory. Nevertheless, it is possible that there are those in possession of radioactive waste that have never contacted Andra, or sites with radioactive contamination that have not yet been identified.

For polluted sites, historical surveys are conducted to identify potentially contaminated sites that have been forgotten over time. Among the recommendations made by the HCTISN in answer to the Minister of State's request[VI], recommendation 15 states that: "The High Committee recommends that the BASIAS site developed by the ministry responsible for ecology in connection with former industrial or service activities should be extended to industrial sites likely to be affected by radioactive contamination." Implementation of this recommendation could well give rise to new historical surveys.

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.

[VI] Opinion on radioecological monitoring of groundwater near nuclear facilities and the management of former radioactive waste storage sites -18 recommendations to improve information, transparency and coordination with stakeholders... Can be consulted at www.developpement-durable.gouv.fr or www.hctisn.fr

APPENDIX 2

ACTIVITY OF RADIOACTIVE WASTE

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1. RADIOACTIVITY

In nature, most atomic nuclei (that constitute matter) are stable. The others have unstable nuclei: they have excess particles (protons, neutrons or both) that cause them to transform (by decay) into other nuclei (stable or unstable). They are said to be radioactive, since during transformation they emit radiation whose nature and properties vary.

2. RADIATION

There are three types of radiation, corresponding to three forms of radioactivity:

RADIATION

α radiation

Emission of a helium nucleus (composed of 2 protons and 2 neutrons) also known as an "a particle". These particles are stopped after travelling several centimetres in the air or by a simple sheet of paper.

β radiation

Transformation of a neutron into a proton accompanied by the emission of an electron. Aluminium foil or a pane of ordinary glass are sufficient for interrupting the path of electrons.

γ radiation

Emission of electromagnetic radiation, of the same nature as visible light and X-rays, but with much more energy and thus more penetrating. Several centimetres of lead or decimetres of concrete are required to stop them.



alpha (helium nucleus)



3. ACTIVITY LEVEL AND LIFETIME

Certain isotopes of elements are very radioactive (billions upon billions of becquerels), while other have low activity (measured in thousands of becquerels). These radioactive particles are called radionuclides.

In addition, the lifetime of radionuclides (period during which they emit radiation) varies greatly from one radionuclide to another. Radioactive half-life is the time taken for the activity of radioactive material to fall to half its original value. Thus, at the end of 10 radioactive half-lives, the radioactivity of a product is divided by 1,000.

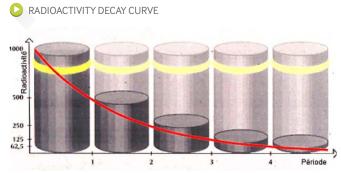
The half-life may range for example from a fraction of a second for polonium-214 to 4.5 billion years for uranium-238.

The radioactive half-life of a radionuclide has an inverse relationship to activity: the longer the half-life, the lower the specific activity. The following table gives examples of activities for 1 gramme of matter (lodine-131, Caesium-137, Plutonium-239 and Uranium-238).

DEFINITION: SPECIFIC ACTIVITY

In nuclear physics, activity is often expressed with volume (activity concentration in Bq/l or Bq/m³), mass (specific activity in Bq/g) or surface area (surface activity in Bq/cm²).

Specific activity is the number of decays of a radioactive substance per unit of time and unit of mass. In the Catalogue of Families, it is expressed in becquerels per gram of finished package.



Radioactivity is divided by four after two half-lives, by eight after three half-lives...

EXAMPLES OF THE RELATIONSHIP BETWEEN HALF-LIFE AND RADIOACTIVITY

Radionuclide	Half-life	Specific activity
lodine-131	8 days	4.6 million billion Bq/g
Caesium-137	30 years	3,200 billion Bq/g
Plutonium-239	24,113 years	2.3 billion Bq/g
Uranium-238	4.5 billion years	12,400 Bq/g

4. DAUGHTER RADIONUCLIDES IN SECULAR EQUILIBRIUM

Radioactive atoms are transformed during decay to become other radioactive or stable atoms. This natural phenomenon takes place in an order and period of time that is specific to each radionuclide. It is called the "decay chain".

In each decay chain, the initial radionuclide is known as the "parent radionuclide". Each intermediate radionuclide produced by decay is called a "radionuclide daughter". At the end of the decay chain, the final result is a stable atom.

When the parent half-life is very clearly greater than that of the daughters, the activities of the various daughters enter into equilibrium with that of the parent. This secular equilibrium is achieved after a period of time equal to approximately 10 times the half-life of the daughter with the longest half-life. The radioactivity of each of the daughters is then considered as proportional to the that of the parent.

Directive 2013/59/Euratom of 5 December 2013 setting the basic standards to protect health from the dangers resulting from exposure to ionising radiation provides the various secular equilibria to take into consideration.

The following table shows the parent and daughter radionuclides¹ considered for calculating radiological activities for the 2015 edition of the National Inventory:

LIST OF VARIOUS SECULAR EQUILIBRIA TO CONSIDER

Parent radionuclide	Daughter Product
⁵² Fe	^{52m} Mn
^{69m} Zn	⁶⁹ Zn
⁹⁰ Sr	90Y
⁹¹ Sr	91m Y
⁹⁵ Zr	⁹⁵ Nb
⁹⁷ Zr	^{97m} Nb, ⁹⁷ Nb
⁹⁷ Nb	^{97m} Nb
⁹⁹ Mo	^{99m} Tc
¹⁰¹ Mo	¹⁰¹ Tc
¹⁰³ Ru	^{103m} Rh
¹⁰⁵ Ru	^{105m} Rh
¹⁰⁶ Ru	¹⁰⁶ Rh
¹⁰³ Pd	^{103m} Rh
¹⁰⁹ Pd	^{109m} Ag
^{110m} Ag	¹¹⁰ Ag
¹⁰⁹ Cd	^{109m} Ag
¹¹⁵ Cd	^{115m} In
^{115m} Cd	^{115m} In

Parent radionuclide	Daughter Product
^{114m} ln	¹¹⁴ In
¹¹³ Sn	^{113m} In
¹²⁵ Sb	^{125m} Te
^{127m} Te	¹²⁷ Te
^{129m} Te	¹²⁹ Te
^{131m} Te	¹³¹ Te
¹³² Te	132
¹³⁷ Cs	^{137m} Ba
¹⁴⁴ Ce	¹⁴⁴ Pr, ^{144m} Pr
²³² U	²²⁸ Th, ²²⁴ Ra, ²²⁰ Rn, ²¹⁶ Po, ²¹² Pb, ²¹² Bi, ²⁰⁸ Tl
²⁴⁰ U	^{240m} Np ^{, 240} Np
²³⁷ Np	²³³ Pa
²⁴⁴ Pu	²⁴⁰ U, ²⁴⁰ Np, ²⁴⁰ Np
^{242m} Am	²³⁸ Np
²⁴³ Am	²³⁹ Np
²⁴⁷ Cm	²⁴³ Pu
²⁵⁴ Es	²⁵⁰ Bk
^{254m} Es	²⁵⁴ Fm

1 The last elements of the decay chains, which are not radioactive, are not given here.

5. **MEASUREMENT** OF RADIOACTIVITY

Our senses do not perceive radiation from radioactivity. It is measured by quantifying its effects.

The methods employed use the track that radiation leaves in the matter it has penetrated. Detectors currently in use are based on various designs (counters containing a gas, scintillators, semiconductors) but all rely on the same principle: they convert photons or electrons created by radiation into an electric signal to count the number of decays.

2 Units of measure for radioactivity

The becquerel and gray are units of measure for radioactivity and its energy. The sievert is a unit for measuring effects.

Becquerel (Bq)

It measures the level of radioactivity, or activity. It corresponds to the number of atoms that decay per unit of time (second). The previous unit was the curie (Ci): $1 \text{ Ci} = 3.7 \cdot 10^{10} \text{ Bq}$, named after the discoverers of radium, Pierre and Marie Curie.

Gray (Gy)

It measures the quantity of energy absorbed (absorbed dose) by matter (organism or object) exposed to ionising radiation. 1 gray corresponds to the energy absorbed of 1 joule per kilo of matter. The previous unit was the rad: 1 Gy = 100 rad.

Sievert (Sv)

The sievert is used to assess the biological effect of naturally occurring or artificial radiation on people by type of radiation. The previous unit was the rem: 1 Sv = 100 rem.

MAIN QUANTITIES MEASURED

Quantity measured	Definition	Units
Activity	Number of decays per second	Becquerel (Bq)
Absorbed dose	Quantity of energy transferred to matter	Gray (Gy)
Effective dose	Effects of radiation on the organism	Sievert (Sv)

Although the becquerel is a extremely small unit, current measurement devices are sensitive enough to detect radioactivity in optimal conditions. In addition, radioactivity is measured instantly using portable devices on condition that the device is suited to the radiation that is actually present.



Measurement of a waste drum

6. **HOW IS THE** RADIOACTIVITY OF WASTE PACKAGES MEASURED?

Each decay is accompanied by the emission of radiation (gamma) or particles (alpha, beta, neutron). Since their energy represents the decayed nucleus, measuring this radiation (intensity and energy) by suitable, correctly calibrated instruments is necessary to assess the activity of waste and to quantify the various radionuclides.

Measurements are taken using spectrometry on packages and/or samples.

Certain radionuclides are however difficult to measure due to the small quantity or low energy radiation. Correlation factors are then established between the activity of these radionuclides and that of a more easily measured radionuclide, which is used as a tracer.

Distribution of the radioactivity of the various radionuclides in the waste (radiological spectrum) is thus evaluated.

Most often, the producer evaluates the activity of the waste during production or conditioning, but the declaration of activity does not always take into account natural radionuclide decay.

To present uniform data in the Catalogue of Families, Andra provides a radioactivity value per family as of the end of 2013, calculated from the acquired data.

The calculation is carried out on the basis of 144 radionuclides with a lifetime exceeding six months and daughter radionuclides in secular equilibrium, and integrates radioactive decay from the date the waste is produced.

These figures are thus not always directly comparable with those stated by producers.



GLOSSARY & ABBREVIATIONS



	TERMS	DEFINITIONS
A	ACTINIDE	Natural or artificial radionuclide with an atomic number between 89 (actinium) and 103 (lawrencium). For certain authorities, 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 (ZrO2).
	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, 10 ⁶ Bq), gigabecquerel (GBq, one billion, 10 ⁹ Bq), terabecquerel (TBq, one thousand billion, 10 ¹² Bq), petabecquerel (PBq, one million billion, 10 ¹⁵ Bq) or exabecquerel (EBq, one billion billion, 10 ¹⁸ Bq).
	BITUMINISED SLUDGE	Sludge resulting from coprecipitation operations in liquid radioactive effluent treatment plants and conditioned in bitumen.
	BURNUP RATE	Total energy released per unit mass of a nuclear fuel. It is currently expressed as gigawatts-day per tonne of heavy metal (GWd/t).
C	CIGEO	Geological disposal facility.
	CIRES	Waste collection, storage and disposal facility.
	CNE	National Assessment Board.
	CNEF	The National Committee for the Evaluation of Funding the expenses of dismantling basic nuclear installations and the management of spent fuel and radioactive waste is a committee created by the law of 28 June 2006 to audit the funding of nuclear-related expenses over the long term.
	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 the predetermined area.
	CONTAINER	In the nuclear industry, a term referring to a movable sealed vessel used for transport, storage and disposal operations.
	CONTAMINATION (RADIOACTIVE)	Unwanted presence of significant quantities of radioactive substances on the surface or within any environment.
	CSA	CSA waste disposal facility for LILW-SL.

	TERMS	DEFINITIONS
D	DISMANTLING	Technical operations performed to dismantle and possibly scrap nuclear equipment or part of a nuclear facility. In French regulations, term referring to the demolition phase of a nuclear facility, comprising all operations after the decommissioning order.
	DISPOSAL PACKAGE	Additional container into which one or several radioactive waste packages may be placed for disposal at a specific facility. This additional packaging is required for handling, safety and reversibility functions.
	DISPOSING OF RADIOACTIVE WASTE	Operation consisting in placing radioactive waste in a facility specially designed for the potentially definitive disposal of the substances concerned in compliance with human health, safety and environmental protection requirements.
E	ENRICHED RECYCLED URANIUM (ERU)	Enriched uranium obtained through enrichment during spent fuel processing. The term enriched reprocessed uranium is also used.
	ERU FUEL	Enriched reprocessed uranium fuels.
F	FAST NEUTRON REACTOR (FNR)	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.
	FISSILE	Term used to describe a nucleus that is capable of undergoing fission through interaction with neutrons in all energy ranges, particularly thermal neutrons. Actinide nuclei with odd neutron numbers are either fissile (²³³ U, ²³⁵ U, ²³⁹ Pu, ²⁴¹ Pu, etc.) or short-lived ß emitters (²³⁷ U, ²⁴³ Pu, ²⁴⁴ Am, etc.). In the case of the latter, the probability of neutron-induced fission is negligible, even at high flux. 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 99Tc and 129I, have long-lived radioactivity.
	FNR FUEL	Fuels for the Phénix and Supérphenix fast neutron reactors. These are MOX-type fuels.
	FRONT END OF FUEL CYCLE	Nuclear fuel cycle operations from mining to fuel fabrication.
	FUEL (NUCLEAR FUEL)	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)	First generation 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, thus confining 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 (approximately 20,000 tonnes). This graphite contains tritium and long-lived elements (carbon-14, chlorine-36).

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TERMS	DEFINITIONS
HCTISN	High Committee for Transparency and Information on Nuclear Safety.
HEAVY METAL (THM)	In the nuclear fuel field, term generally referring to all actinides. In practice, this expression mainly concerns uranium, plutonium and thorium and is most often expressed in tonnes of heavy metal (tHM).
HLW	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.
IAEA	International Atomic Energy Agency (www.iaea.org).
ICPE	Installation classified on environmental protection grounds.
ILW-LL	Intermediate-level long-lived waste comes primarily 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	Any nuclide of a given element. All the nuclides of a single element.
LILW-SL	Low- and intermediate-level short-lived waste comes primarily 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.
LONG-LIVED WASTE	Radioactive waste in which the main radioactive components are radionuclides with a radioactive half-life greater than 31 years.
MATRIX	Immobilisation or coating material with which waste is fairly closely associated in order to limit the spread of radioactive substances.
"MARKED" SITE	Site exhibiting traces of natural or artificial radionuclides that can be detected without necessarily requiring any specific action.
METASTABLE	State in which an atomic nucleus is "blocked" in an excited state (at an energy level higher than its basic state) for a certain period of time, from several billionths of a second to several billion years.
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 in order not to 'waste' them, and be sufficiently dense to ensure effective slowing down.
MOX FUEL	Abbreviation for mixed-oxide fuel made of plutonium and uranium.
	HCTISNHEAVY METAL (THM)HLWHUULS AND END CAPSIAEAICPEILW-LLINDUSTRIAL VOLUMEISDISOTOPELLW-SLLLW-LLMATRIXMATRIXMATRIXMINOR ACTINIDEMODERATOR

	TERMS	DEFINITIONS
N	NPP	Nuclear power plant.
	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. 23892U.
0	OPECST	Parliamentary Office for the Evaluation of Scientific and Technological Choices
	OPERATING WASTE	Operating waste is produced during operation or dismantling of a facility.
P	PLUTONIUM	Element with atomic number Z = 94. It was initially produced for military 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 reactor studies.
	PNGMDR	French National Radioactive Materials and Waste Management Plan
	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 past human activity. Residual pollution concerns a quantity or concentration of pollutants remaining in a given environment after remediation.
	PRESSURISED WATER REACTOR (PWR)	Synonyme de réacteur à eau sous pression. Thermal neutron reactor using light water as moderator and coolant. This water is maintained in the liquid state inside the reactor core through pressure high enough to prevent bulk boiling at the operating temperature.
	PROVEN POLLUTED SITE	Area polluted by a current or past industrial activity and on which an environmental assessment or action plan has been carried out.
	PUBLIC SERVICE EASEMENT	Public service easements constitute automatic encumbrances on real estate (buildings and land) that have the effect either of curtailing, even prohibiting, the exercise of owners'rights, or imposing the performance of work.
R	RADIOACTIVE CLEANUP	Operations performed in a nuclear facility or site in order 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 "remediation" in the sector of contamination by radioactive substances.
	RADIOACTIVE HALF-LIFE (OR PERIOD)	Interval of time required for one-half of the atomic nuclei of a radionuclide to decay. The radioactivity of a pure sample of a single isotope would then be halved. After 10 such half-lives, the radioactivity would be divided by a factor of 1,000.
	RADIOACTIVE MATERIAL	Radioactive substance for which subsequent use is planned or intended, after processing, if necessary.
	RADIOACTIVE SOURCE	A device, radioactive substance or facility that emits ionising radiation or radioactive substances.

TERMS	DEFINITIONS
RADIOACTIVE SUBSTANCE	Substance containing natural or artificial radionuclides where the activity or concentration justifies radiological protection monitoring.
RADIOACTIVE WASTE	Radioactive waste refers to radioactive materials for which no subsequent use is planned or envisaged. Final radioactive waste is radioactive waste that can no longer be processed by extracting recoverable materials or reducing its polluting or hazardous character under current technical and economic conditions.
RADIOACTIVE WASTE CONDITIONING	Operations intended to prepare radioactive waste for subsequent transport, storage or disposal. Note: These operations may include compaction, embedding, vitrification, cementation, bituminisation and containerisation.
RADIOACTIVE WASTE DISPOSAL FACILITY	Facility intended for long-term 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 HOLDER	Waste producer or any other person in possession of waste (L. 541-1-1).
RADIOACTIVE WASTE PACKAGE	Conditioned and packaged radioactive waste.
RADIOACTIVITY	Property of a nuclide that allows it to undergo spontaneous transformation (into another nuclide) with emission of radiation (particles, X-rays, gamma rays, etc.), or spontaneous fission with emission of particles and gamma rays. In addition to spontaneous fission, the main forms of radioactivity are beta radioactivity (B+, B-, internal conversion), gamma radioactivity and electron-capture radioactivity. Gamma radioactivity often accompanies the other forms.
RADIOELEMENT	Chemical element of which all isotopes are radioactive. 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 atoms that undergo radioactive decay and emit radiation, which is the origin of the phenomenon of radioactivity.
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 cleanup and redevelopment operations carried out to make a site suitable for a given use.

S	

TERMS	DEFINITIONS
SCENARIO	Set of assumptions regarding events or types of behaviour used to describe the possible changes 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.
SIENID	Sites and installations for defence-related nuclear experiments.
SOURCE BLOCK PACKAGE	These ILW-LL category packages contain spent sealed sources collected from small-scale nuclear activities 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 in 1994.
SPENT FUEL	Nuclear fuel discharged from a reactor after irradiation and sent to a waste storage centre, repository or processing site.
SPENT FUEL PROCESSING	Operations performed on spent fuel from nuclear reactors in order to extract recoverable materials (e.g. uranium and plutonium) and condition the remaining waste. Spent fuel processing may also be performed to separate other elements.
SPM	Suspended particulate matter, residues from the processing of rare earths containing thorium.
STORAGE (OF RADIOACTIVE MATERIAL OR WASTE)	The temporary placement of radioactive matter or waste in a specially designed facility, pending subsequent retrieval.
STRUCTURAL WASTE	Radioactive waste composed of metallic structures of spent fuel assemblies from pressurised water reactors. This term is also used to refer to spent fuel assemblies from sodium-cooled fast reactors.
TENORM WASTE	Technologically enhanced, naturally occurring radioactive material waste is generated by the transformation of raw materials containing naturally-occurring radionuclides that are not used for their radioactive properties; the radionuclides are concentrated in materials or waste after processing.
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 affect (case of a toxic with threshold effect), or between a dose and probability of effect (case of toxic without threshold effect), or between a dose and probability of effect (case of 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 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.

	TERMS	DEFINITIONS
U	UOX FUEL	 Nuclear fuel made from uranium oxide. There are various 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	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 results primarily 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.
	VOLUME AS DISPOSED	Unit used to prepare the statements. It allows the waste to be accounted for using a single, common unit. Forecasts also use the unit of volume as disposed. For waste for which the conditioning is not yet known, assumptions are performed to assess the volume as disposed. In the specific case of deep geological disposal, additional packaging may be necessary for handling, safety or reversibility purposes. At this stage in the design studies, the volume of disposal packages compared with the volume of primary packages is on the order of a factor of 2 to 3 for HLW and on the order of a factor of 4 for ILW-LL. Only the volume of primary packages is indicated in this document.
	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 RECOVERY AND CONDITIONING	Waste from waste recovery and conditioning consists of waste that has not been conditioned during production and which is or will be conditioned and disposed by those in possession of them.
	WASTE TREATMENT	Mechanical, physical or chemical operations intended to modify the characteristics of waste materials.
	WASTE WITH HIGH NATURAL RADIOACTIVITY	Waste with high natural radioactivity is generated by the use or processing of raw materials containing naturally-occurring radionuclides that are not used for their radioactive properties. This waste includes technologically-enhanced, naturally-occurring radioactive material (TENORM) and may require special management.
Z	ZIRCON	Zircon is a natural silicate ore (ZrSiO4).

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