

ESSENTIALS

National Inventory of Radioactive Materials and Waste

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EDITORIAL

In the early 1990s, the French government made Andra a public agency, independent from radioactive waste producers, and tasked it with identifying and designing safe management solutions for all French radioactive waste, in order to protect current and future generations. As part of its public interest role, Andra is also responsible for regularly completing the *National Inventory of Radioactive Materials and Waste* on French territory.

“ This National Inventory constitutes a valuable tool for guiding French policy regarding the management of radioactive materials and waste. ”

Through the *National Inventory*, a key reference resource, Andra provides the most comprehensive, exhaustive possible overview of the quantities of radioactive materials and waste, on an annual basis. It also provides, every three years, projected estimates of the quantities of materials and waste based on several contrasting scenarios relating to the future of nuclear facilities and France's long-term energy policy. All the data are available on the website: inventaire.andra.fr, while the radioactive waste inventory is also made available to the public as open data on the data.gouv.fr website.

In the interests of transparency, Andra has set up an interdisciplinary steering committee to monitor the preparation of the *National Inventory*, and annually reports the quantity of materials and waste to the working group of the National Radioactive Materials and Waste Management Plan (PNGMDR). This working group, co-chaired by the Nuclear Safety Authority (ASN) and the Directorate-General for Energy and Climate (DGEC), comprises representatives of the administration, the safety authorities, radioactive waste managers, associations and civil society.

With this document, *Essentials 2018*, our aim is to provide an accessible overview of radioactive materials and waste, the related management principles, the inventory on French territory as of 31 December 2016, and projected inventories.

It is supplemented by the publication of a summary report that includes new thematic dossiers on waste from the medical sector and the sites polluted by radioactivity, as well as a revised edition of the thematic dossier on sealed sources, and updates to the geographical inventory and the catalogue of waste families on the website. New functions will also be added to the website to make it even easier for you to access the data regarding radioactive materials and waste.

Happy reading!



PIERRE-MARIE ABADIE
Chief Executive Officer, Andra

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The figures given in this document have been rounded. They reflect the situation on 31 December 2016 and have been established on the basis of the reports made by the holders of radioactive materials and waste.

The data are detailed in the summary report of the 2018 edition of the National Inventory.

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RADIOACTIVE MATERIALS AND WASTE AND THEIR MANAGEMENT METHODS

SECTORS USING RADIOACTIVITY

Various economic sectors use radioactive materials. These sectors produce radioactive waste and use radioactive materials. As this radioactivity can present a health risk, radioactive materials and waste are subject to special management procedures.

In France, radioactive materials and waste management principles form part of a strict regulatory framework, established at national level (Act 2006-739 of 28 June 2006, which notably resulted in the National Radioactive Materials and Waste Management Plan, PNGMDR) and international level (European Council Directive 2011/70/ Euratom of 19 July 2011).



NUCLEAR POWER INDUSTRY

Mainly nuclear power plants for electricity production, as well as facilities dedicated to producing nuclear fuel (mining and processing of uranium ore, chemical conversion and enrichment of uranium concentrate), reprocessing spent fuel and recycling a portion of the materials extracted from spent fuel.



NON-NUCLEAR-POWER INDUSTRY

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



A radioactive substance is a substance that contains natural or artificial radionuclides, the activity or concentration of which justifies radiological protection monitoring.

Article L.542-1-1 of the French Environmental Code



RESEARCH

Research for civil nuclear applications, in addition to research in the fields of medicine, nuclear and particle physics, agronomy, chemistry and biology, among others.



DEFENCE

Mainly deterrence activities, including nuclear propulsion for certain ships and submarines, as well as associated research and the activities of the armed forces.



HEALTHCARE

Diagnostic and therapeutic activities (scintigraphy and radiotherapy, among others).

RADIOACTIVE MATERIALS AND THEIR MANAGEMENT METHODS

OVERVIEW OF RADIOACTIVE MATERIALS

A radioactive material is a radioactive substance for which subsequent use is planned or intended, after processing if necessary (article L.542-1-1 of the French Environmental Code).

NATURAL URANIUM



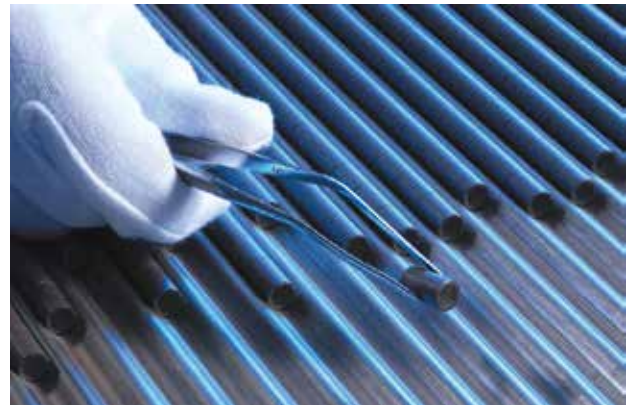
Yellowcake

- **Natural uranium extracted from the mine:** uranium is a naturally-occurring radioactive metal found in certain rocks in the form of an ore. It is mined, processed and formed into a solid uranium concentrate known as yellowcake. There are no longer any open uranium mines in France – all uranium comes from abroad.
- **Enriched natural uranium**, obtained by increasing the uranium 235 concentration of natural uranium – this is used to manufacture fuel for nuclear reactors.
- **Depleted uranium**, obtained during the natural uranium enrichment process – this is transformed into a solid, chemically stable, incombustible, insoluble and non-corrosive material in the form of a black powder. It is used to manufacture uranium and plutonium mixed oxide fuel (MOX).

URANIUM FROM SPENT FUEL REPROCESSING

Reprocessed uranium (RepU), recovered during the reprocessing of spent fuel, can be used to make new fuel.

NUCLEAR FUEL



Fuel pellets

Nuclear fuel is mainly used in nuclear power plants.

It comprises:

- mostly **enriched natural uranium fuel (ENU)** made from uranium oxide;
- to a lesser extent, **enriched reprocessed uranium (ERU)** fuel made from uranium oxide from reprocessed uranium;
- **MOX fuel, made from mixed uranium and plutonium oxide**, used in certain nuclear plants.

It also includes:

- **fuel** used in research reactors;
- **fuel for defence purposes**, used for deterrence activities and in onboard reactors for nuclear propulsion;
- **fuel for fast neutron reactors (FNR) made from mixed uranium and plutonium oxide**, for the Phénix and Superphénix reactors, which have been permanently shut down and are therefore no longer used.

This fuel may be new, in use, spent and awaiting reprocessing, or in the form of scrap.

PLUTONIUM

Plutonium is an artificial radioactive element generated by the operation of nuclear reactors. Like uranium, it can be recovered when spent fuel is reprocessed. It is then used to manufacture uranium and plutonium mixed oxide fuel (MOX).

MATERIALS ASSOCIATED WITH THE EXTRACTION OF RARE EARTH METALS



Madagascar monazite

Rare earth metals (metals naturally present in the Earth's crust) are extracted from ores such as monazite and used in numerous applications (electronic equipment, automotive catalytic converters, and so on).

When they are processed, the following materials are produced:

- **thorium**, a by-product of concentration, which is stored pending a possible future use;
- **materials in suspension**, from the processing and neutralisation of chemical effluents, which are composed of rare earth residues that will be reused.

METHODS FOR MANAGING RADIOACTIVE MATERIALS

Radioactive materials are stored in facilities suited to their characteristics until they can be used or reused. For certain materials, such as plutonium from the reprocessing of spent uranium oxide fuel, a system to reuse them in industry has already been in place for more than thirty years: these materials are recycled since they are recoverable.

For other materials, reuse is only a potential future process – the PNGMDR requires the owners of radioactive materials and waste to regularly check whether stored materials are recoverable.



Spent fuel storage pool at the Orano (formerly Areva) reprocessing plant at La Hague



The storage of radioactive materials or waste is the operation consisting in temporarily placing these radioactive substances in a surface or near-surface facility specially designed for this purpose, with the intention to retrieve them at a later date.

Article L.542-1-1 of the French Environmental Code

RADIOACTIVE WASTE AND ITS MANAGEMENT METHODS

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

In general, radioactive waste contains a mix of radionuclides (namely radioactive isotopes: caesium, cobalt, strontium, etc.). Depending on its composition, the waste has higher or lower levels of radioactivity lasting for varying periods of time. It is divided into six categories.



Radioactive waste is produced during the operation of facilities using radioactive substances, and also when these facilities are dismantled.

CLASSIFICATION OF RADIOACTIVE WASTE AND ASSOCIATED MANAGEMENT SOLUTIONS

Category	Very short-lived waste	Short-lived waste	Long-lived waste
Very low-level waste (VLLW)	 Management through radioactive decay	 Surface disposal (industrial facility for grouping, storage and disposal)	
Low-level waste (LLW)		 Surface disposal (Aube and Manche disposal facilities)	 Near-surface disposal under development
Intermediate-level waste (ILW)			 Deep geological disposal under development (Cigéo project)
High-level waste (HLW)	Not applicable		

Certain waste may sometimes be classified in a set category but managed using another management solution due to other characteristics (for example its chemical composition or its physical properties).




Radioactive half-life

Radioactive half-life expresses the time it takes for the initial activity of a given radionuclide to be halved. A distinction is drawn between:

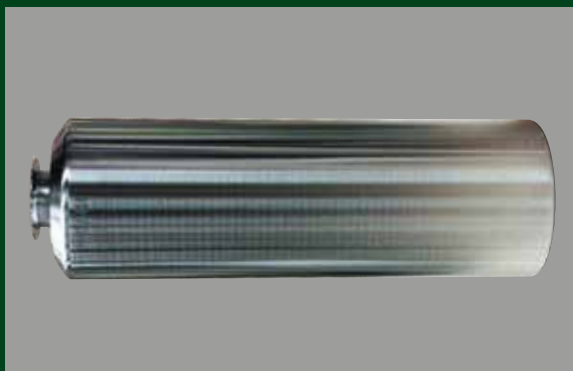
- very short-lived waste (VSLW), which contains radionuclides with a half-life of less than 100 days. It can only be directed to a conventional waste management solution after a period of more than ten times the radionuclide half-life, i.e. around three years;
- short-lived (SL) waste, whose radioactivity comes mainly from radionuclides with a half-life of less than or equal to 31 years;
- long-lived (LL) waste, which contains a significant quantity of radionuclides with a half-life of more than 31 years.

DESCRIPTION OF RADIOACTIVE WASTE CATEGORIES

HLW HIGH-LEVEL WASTE




-  **High: several billion Bq/g**
-  **Up to very long (up to several hundreds of thousands of years)**
-  **Deep geological disposal under development¹**

This waste principally comes from the reprocessing of spent fuel² (after use in a nuclear reactor). It is made up of highly radioactive residues from the chemical dissolution of spent fuel. This waste is incorporated in glass then conditioned in stainless steel containers.



HLW packages

ILW-LL INTERMEDIATE-LEVEL LONG-LIVED WASTE




-  **Intermediate: a million to a billion Bq/g**
-  **Long to very long (up to several hundreds of thousands of years)**
-  **Deep geological disposal under development¹**

This is mostly waste from the metal structures surrounding the fuel (hulls and end caps), which comes from the reprocessing of spent fuel² and, to a lesser extent, the technological waste associated with the use and maintenance of nuclear facilities, the waste from the treatment of liquid effluents (bituminised sludge) and activated waste from inside nuclear reactors.



End-pieces from the zirconium alloy cladding that holds the fuel pellets.

LLW-LL LOW-LEVEL LONG-LIVED WASTE

-  **Low: a few tens to several hundreds of thousands of Bq/g**
-  **Long to very long (up to several hundreds of thousands of years)**
-  **Disposal under development**



Graphite sleeve with wire locks




This includes:

- graphite waste from the operation and dismantling of the first nuclear plants;
- radium-bearing waste, chiefly from non-power-generating industrial activities such as the extraction of rare earth metals;
- other types of waste, such as certain items of legacy waste conditioned in bitumen, and uranium conversion residues from the Orano (formerly Areva) plant at Malvési (see page 16), and waste from the operation of the La Hague reprocessing plant.

¹ Cigéo project

² The reprocessing of spent fuel makes it possible to separate recoverable materials (plutonium and uranium) from the final waste that constitutes HLW and ILW-LL. These materials can be recycled to produce new fuel. The waste is stored at the reprocessing sites pending disposal.

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




-  **Low to intermediate: a few hundreds to a million Bq/g**
-  **Short (up to around 300 years)**
-  **Existing surface disposal¹**

This principally comes from operations (the processing of liquid effluents or filtration of gaseous effluents, etc.), maintenance (clothing, tools, gloves, filters, etc.) and the dismantling of nuclear plants, fuel cycle facilities and research centres. A small portion of it may also come from medical research activities.



Waste from the use of radioactive products in a laboratory

VLLW VERY LOW-LEVEL WASTE

-  **Very low: less than 100 Bq/g**
-  **Not a determining factor²**
-  **Existing surface disposal³**




This mainly comes from the operation, maintenance and dismantling of nuclear plants, fuel cycle facilities and research centres.

VLLW usually takes the form of inert waste (concrete, rubble, earth, etc.) or metal or plastic waste.



Waste rubble from dismantling




VSLW VERY SHORT-LIVED WASTE

-  **Very low to intermediate**
-  **Very short (up to around three years)**
-  **Management through decay**

This mostly comes from the medical or research sectors. Medical waste may constitute liquid or gaseous effluents, or contaminated solid or liquid waste generated by the use of radionuclides in this domain.



Decay containers

 Radioactivity level  Time needed for the radioactivity to decay (to a level that presents no risks to human health or the environment) – this depends on the half-life.  Final waste management method.

¹ Aube (CSA) and Manche (CSM) disposal facilities.

² Given its very low level, the time criterion is not taken into account when classifying this waste category.

³ Industrial facility for grouping, storage and disposal (Cires) in the Aube.

RADIOACTIVE WASTE MANAGEMENT METHODS

In order to isolate waste for the time needed for its radioactivity to decay to a level that poses no risk to human health or the environment, France has decided to manage it in dedicated disposal facilities, potentially after a prior storage period.

There are currently three types of disposal facility in existence or under development. They are engineered for the radioactivity level and longevity of the waste they will host.

- Surface disposal facilities: two facilities operated by Andra in the Aube department are used for very low-level waste (VLLW) and low- and intermediate-level short-lived waste (LILW-SL). There is also the Manche disposal facility, which was in operation from 1969 to 1994 and is currently in the post-closure monitoring phase.
- Near-surface disposal facility, under development, for the disposal of low-level long-lived waste (LLW-LL).
- Deep geological disposal facility, under development, for the disposal of high-level (HLW) and intermediate-level long-lived waste (ILW-LL).

These last two types of disposal facility are under development by Andra, in accordance with the provisions of the Act of 28 June 2006.

The initial choice of a management solution depends on the waste characterisation studies and processing and conditioning methods. The final decision is based on the characteristics of the package produced.

In addition, for very short-lived waste (VSLW), the radioactivity drops significantly in a few months, or even a few days or hours.



The disposal of radioactive waste is the operation consisting in placing these substances in a facility that has been specially designed to hold them on a potentially permanent basis [...], without the intention to retrieve them at a later date.

Article L.542-1-1 of the French Environmental Code



Disposal of waste packages in the disposal vaults at the Aube disposal facility (CSA)

It is therefore stored on site until radioactive decay has occurred, then disposed of using the conventional waste solution suitable for its physical, chemical and biological characteristics.

Finally, certain items of radioactive waste cannot yet be treated and conditioned in a way that makes them suitable for an identified management solution, notably due to their special physical or chemical characteristics. By convention, this is referred to as “orphan” waste (DSF). After any required treatment, conditioning or characterisation, this orphan waste is sent to the appropriate management solution.

FOCUS ON THE PRODUCTION OF RADIOACTIVE MATERIALS AND WASTE BY THE FRENCH NUCLEAR POWER SECTOR

Most radioactive materials and waste produced by the nuclear power sector come from running the facilities that manufacture, use and then reprocess nuclear fuel.

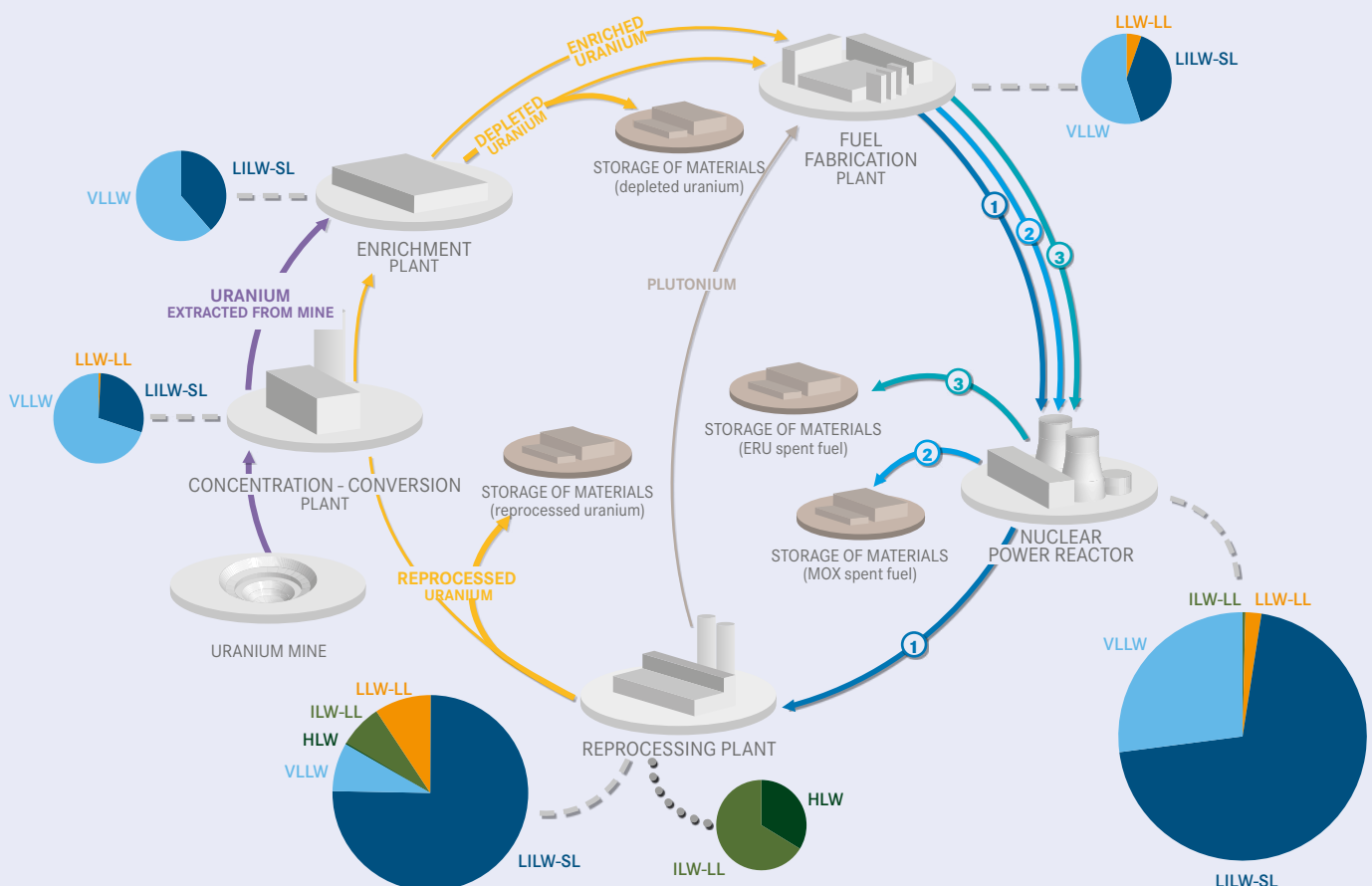
This includes the operation of the facility and its dismantling.

Most of the waste produced by facility operation is very low-level waste (VLLW) and low- and intermediate-level short-lived waste (LILW-SL). This is taken to Andra's industrial facilities in the Aube (Cires and CSA). A lower quantity of intermediate-level long-lived waste (ILW-LL) and high-level waste (HLW) is produced, and this is stored at the production site pending the creation of a disposal facility able to receive it: Cigéo. The nuclear power sector generates a small amount of low-level long-lived waste

(LLW-LL), for which a disposal facility is also under development.

The dismantling of these facilities also produces waste, the vast majority of which is very low-level waste (VLLW).

Radioactive materials are currently recovered or stored pending recovery in the future. For example, reprocessed uranium (RepU) could be used in nuclear power reactors in the form of enriched reprocessed uranium (ERU). Research is being conducted on a cycle that includes sodium-cooled fast reactors, which would make it possible in the future to improve the recycling of materials, notably those from the reprocessing of MOX and ERU fuel, as well as depleted uranium.



- ① Enriched natural uranium oxide fuel (ENU)
- ② Uranium and plutonium mixed oxide fuel (MOX)
- ③ Enriched reprocessed uranium oxide fuel (ERU)



— Operation and dismantling waste - Inventory at the end of 2016

- - - Residual waste after the reprocessing of spent fuel - Inventory at the end of 2016

2

INVENTORY OF RADIOACTIVE MATERIALS AT END OF 2016

MATERIALS RECORDED

Andra performs an annual inventory of all the radioactive materials present on French territory as of 31 December of every year, based on the information provided by the holders of these materials. These are substances for which a later use is planned or envisaged, after reprocessing if necessary, with the exception of sealed sources, which are registered by the French Institute for Radiological Protection and Nuclear Safety (IRSN) in virtue of article R.1333-47 of the French Public Health Code.

For fissile materials, the main holders of materials are players in the nuclear fuel cycle, all operators of nuclear reactors (power, defence or research facilities) and players in the chemical industry who hold radioactive materials as part of their activities (the mining of rare earth metals, for example).

The foreign materials present on French territory referred to in article L.542-2-1 of the Environmental Code are also counted in the records.



The unit used to present the quantities of radioactive materials is the tonne of heavy metal (tHM), which represents the quantity of uranium, plutonium or thorium contained in the materials, except in the case of fuel for defence purposes, which is expressed in tonnes of assemblies (t).



Crystals of uranium hexafluoride

INVENTORY OF RADIOACTIVE MATERIALS

The table below shows the inventory of radioactive materials at the end of 2016 and the changes from the previous National Inventory.

► INVENTORY OF RADIOACTIVE MATERIALS (IN tHM, EXCEPT IN THE CASE OF SPENT FUEL FOR DEFENCE PURPOSES IN TONNES OF ASSEMBLIES)

Category of material		End of 2016	2016-2013 change*
Natural uranium	Mined natural uranium, in all its physicochemical forms	29,900	+ 3,810
	Enriched natural uranium, in all its physicochemical forms	3,860	+ 1,090
	Depleted uranium, in all its physicochemical forms	310,000	+ 23,500
Uranium from spent fuel reprocessing	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 ¹	29,600	+ 2,690
Uranium oxide fuel from nuclear power reactors (ENU, ERU)	Fuel before use	448	+ 3
	Fuel in use in nuclear power plants	4,500	- 55
	Spent fuel awaiting reprocessing	12,000	- 392
	Non-irradiated uranium fuel scrap awaiting reprocessing	-	-
Uranium and plutonium mixed oxide fuel from nuclear power reactors (MOX, FNR)	Fuel before use or in production	38	0
	Fuel in use in nuclear power plants	430	+ 16
	Spent fuel awaiting reprocessing	1,960	+ 297
	Non-irradiated fuel scrap awaiting reprocessing ²	267	+ 33
Research reactor fuel	Fuel before use	-	- 0.2
	Fuel in use	0.8	+ 0.6
	Other spent civil fuel	59	- 16
Non-irradiated separated plutonium, in all its physicochemical forms		54	+ 2
Thorium, in the form of nitrates and hydroxides		8,570	+ 45
Materials in suspension (by-products of rare earth ore processing)		5	0
Other materials ³		70	- 2
Spent fuel for defence purposes		177	+ 21

The changes have been calculated on the basis of the exact figures, then rounded.

In the context of nuclear power generation, radioactive materials are used as fuel, processed or stored (pending recovery). The change in inventory levels corresponds to three years of operation of the nuclear power plant fleet, as well as:

- a change in the scope for reporting research reactor fuel;
- from the 2016 report onwards, taking into account the radioactive decay of the plutonium in the second Superphénix core in the "Other materials" category.

¹ Uranium from spent fuel reprocessing intended for enrichment to form enriched uranium from spent fuel reprocessing, which will then be used to make enriched reprocessed uranium oxide fuel (ERU).

² The scrap from non-irradiated mixed uranium-plutonium fuel awaiting reprocessing will eventually be reprocessed and recycled in nuclear power reactors.

³ The second Superphénix core, which was not and will not be irradiated, was classified in the "Other materials" category as it does not correspond to either "fuel before use" or "spent fuel".

3

INVENTORY OF RADIOACTIVE WASTE AT END OF 2016

Andra performs an annual inventory of all the radioactive waste present on French territory as of 31 December of every year, based on the information provided by the holders of this waste. There are more than 1,000 waste holders across all economic sectors, a minority of whom hold the majority of radioactive waste.

The foreign waste referred to in article L.542-2-1 of the Environmental Code, which is to be returned to foreign customers, is included in this inventory if it is present on French territory on the reference date.



Disposal of LILW-SL waste packages at the Aube disposal facility

WASTE ALREADY DISPOSED OF OR DUE TO BE MANAGED BY ANDRA

The volumes of waste listed correspond to the volumes of conditioned waste, i.e. waste that the producers do not intend to process further before disposal. This conditioned waste constitutes primary packages.

For inventory purposes, a uniform counting unit has been adopted: "conditioned equivalent volume".

For waste that has not yet been conditioned, the conditioned equivalent volume is estimated.

In the specific case of the Cigéo geological disposal project (which will receive high-level waste (HLW) and intermediate-level long-lived waste (ILW-LL)), an additional conditioning stage, known as the disposal package, may be necessary for handling or retrievability functions in particular. Only the volume of primary packages is taken into account in this document.

The data below correspond to the radioactive waste already disposed of at Andra facilities, or due to be managed by the Agency.

► INVENTORY AND CHANGE IN VOLUMES (m³) OF WASTE ALREADY DISPOSED OF OR DUE TO BE MANAGED BY ANDRA

Category	End of 2016	2016-2013 change*
HLW	3,650	+ 440
ILW-LL	45,000	+ 1,260
LLW-LL	90,500	- 570
LILW-SL	917,000	+ 39,600
VLLW	482,000	+ 46,200
DSF	1,800	- 1,970
Total	~ 1,540,000	~ + 85,000

The changes have been calculated on the basis of the exact figures, then rounded.

The changes observed between the quantity of waste at the end of 2013 and that at the end of 2016 can be explained by:

- ongoing waste production;
- a new conditioning scenario for the conditioning of Orano (formerly Areva) LLW-LL waste at La Hague, in accordance with the waste studies sent to ASN. However, this change does not correspond to a decrease in the quantity of radioactive waste;
- asbestos waste now generally being reported in the VLLW category, following the recommendation of the working group on DSF waste to remove asbestos waste from this category;
- the identification of a management solution for some of the DSF waste, oriented towards the VLLW and LILW-SL categories.



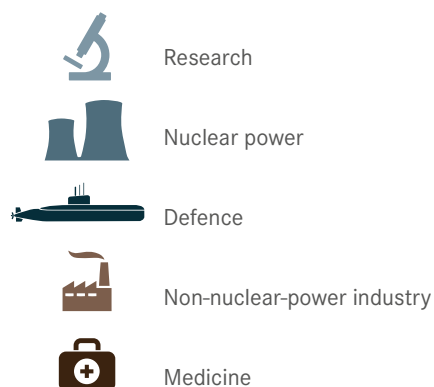
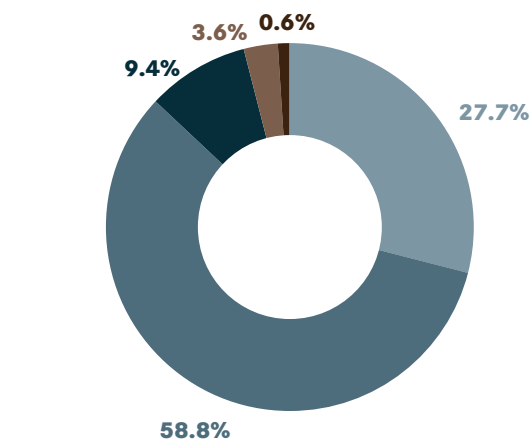
Conditioning is the operation consisting in placing waste in a container suited to its radioactivity level and half-life, then immobilising it, if necessary, in an immobilisation or embedding material.

► INVENTORY OF VOLUMES (m³) OF WASTE AT PRODUCER/HOLDER SITES AND DISPOSED OF AT ANDRA FACILITIES AT THE END OF 2016

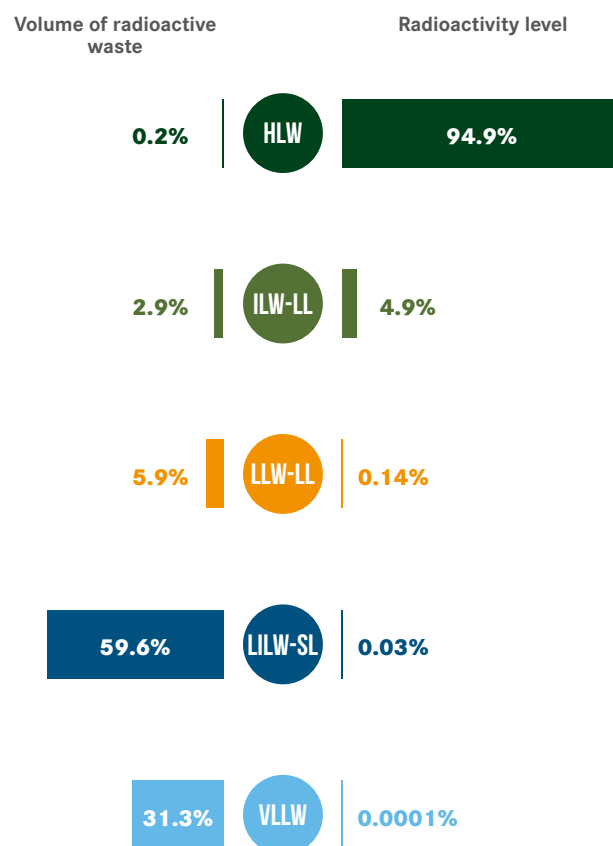
Category of radioactive waste	Total	At producer/holder sites	Disposed of at Andra facilities	Existing disposal capacity
HLW	3,650	3,650	0 ¹	0 ¹
ILW-LL	45,000	45,000	0 ¹	0 ¹
LLW-LL	90,500	90,500	0 ¹	0 ¹
LILW-SL	917,000	74,100	843,000	1,530,000
VLLW	482,000	154,000	328,000	650,000
DSF	1,800	1,800	-	-

LILW-SL and VLLW is stored at the production site for retrieval, conditioning or removal to Andra disposal facilities.

► BREAKDOWN BY ECONOMIC SECTOR OF VOLUME OF WASTE (CONDITIONED EQUIVALENT VOLUME) ALREADY DISPOSED OF OR DUE TO BE MANAGED BY ANDRA, END OF 2016



► BREAKDOWN BY VOLUME AND RADIOACTIVITY LEVEL OF RADIOACTIVE WASTE, END OF 2016



¹ This waste has not yet been disposed of: the disposal of HLW and ILW-LL is currently under development (Cigéo). The disposal of LLW-LL waste is also under development. Orphan waste (DSF) will be directed to a management solution after any necessary treatment or characterisation.

VERY SHORT-LIVED WASTE

► INVENTORY AND CHANGE IN VOLUMES (m³) OF VERY SHORT-LIVED WASTE MANAGED THROUGH DECAY

	End of 2016	2016/2013 change*
VSLW	1,950	- 200

The quantity of very short-lived waste is almost stable in comparison to 2013. These volumes are not included in the inventory.

SPECIFIC CASE OF WASTE FROM MALVÉSI

Uranium conversion treatment residues (RTCU) from the Orano (formerly Areva) plant at Malvési partly comprise legacy waste. Work is under way to find a safe, long-term management solution at the Malvési site for legacy RTCU waste due to its specific nature (large volumes, etc.). RTCU waste produced after 2019 will no longer be managed alongside legacy RTCU, and should be directed towards VLLW and LLW-LL management solutions after treatment and conditioning.

► INVENTORY AND FORECASTS FOR VOLUMES OF URANIUM CONVERSION TREATMENT RESIDUES (RTCU) STORED AT THE MALVÉSI SITE (m³)

	End of 2016	End of 2030	End of 2040
Settling ponds	70,400	0	0
Legacy RTCU	282,000	310,000	310,000
LLW-LL RTCU	0	24,000	40,000
Nitrated effluents	374,000	200,000	110,000

These volumes are not included in the inventory and forecasts.

The changes in the quantities can be explained by:

- the drainage of the sludge in the settling ponds and the recategorisation of this sludge after treatment as legacy RTCU and LLW-LL RTCU;
- the production of LLW-LL RTCU;
- from 2020, the thermal treatment of nitrated effluents, resulting in a reduction in their volume and the production of VLLW waste (not taken into account here, but taken into account in the forecasts for VLLW waste).

WASTE PROCESSED USING SPECIFIC MANAGEMENT METHODS

(this waste is not included in the inventory)

- **Waste disposed of inside or near the perimeter of nuclear facilities or plants.** Its activity is in the order of a few becquerels per gram (several thousands of tonnes).
- **Residues from processing uranium ores** present on former mining sites. These are long-lived residues with an activity level comparable to that of VLLW (approximately 50 million tonnes).



Former mine at Bellezane

- **Waste disposed of in conventional waste disposal facilities.** Some of these facilities have received waste with low quantities of radioactivity, around a few becquerels per gram (approximately 3,000 tonnes).

- **Waste with high natural radioactivity managed through onsite disposal.** This is generated by the processing of raw materials that contain naturally-occurring radionuclides, but which are not used for their radioactive properties. Most of this waste is comparable to VLLW (around 50 million tonnes).



The Solvay plant produced residues from the treatment of natural materials that are very slightly radioactive. These were used as backfill at the La Pallice port in La Rochelle.

- **Waste dumped at sea.** Dumping radioactive waste at sea was a management solution considered safe by the international scientific community, as the dilution and assumed duration of isolation provided by the marine environment were deemed sufficient. As a result, between 1946 and 1993, several countries dumped radioactive waste at sea. Several thousands of tonnes of waste were dumped at sea by France between 1967 and 1982. Since 1993, dumping radioactive waste at sea has been completely prohibited.

Disposal sites (except those at sea) undergo environmental monitoring, which makes it possible to check that the potential impact of this waste is under control.

4

PROJECTED INVENTORIES

The purpose of the projected inventories is to provide an estimate of the quantities of radioactive materials and waste at different timescales based on several scenarios. They aim to present the impact of different strategies or potential changes in French energy policy over the long term on the quantities of radioactive materials and waste, without anticipating the industrial decisions that may be made.

They meet the requirements of the French National Radioactive Materials and Waste Management Plan (PNGMDR) for 2016-2018.

France currently runs a nuclear power plant fleet of 58 reactors in operation, with one EPR™ reactor under construction, and French energy policy provides for the reprocessing of fuel after its use in nuclear plants.

The projected inventories have been drawn up based on four different scenarios representing a change from current energy policy: three scenarios in which the French nuclear power plant fleet is renewed and one scenario in which it is not. The non-renewal scenario assumes that the nuclear programme is cancelled. The three renewal scenarios assume different operating periods for current reactors. They also assume that new reactors will be deployed, with different assumptions made regarding the type of reactor (EPR™/FNR or just EPR™).

The quantities of radioactive waste and materials that could be reclassified as waste are estimated at the end of facility life for each of the scenarios on the basis of information provided by their holders. The reports made



Nuclear plant: cooling towers

cover all radioactive substances that have been and will be produced by the facilities licensed as of the end of 2016 (existing fleet).

The materials and waste generated by the operation of new reactors replacing the reactors in the current nuclear power plant fleet are not included¹.

In addition, the materials generated by the current fleet and which could be consumed in new reactors are not counted as waste.

The term "at the end of facility ...e" means after the dismantling of the nuclear facilities licensed as of the end of 2016.

¹ The estimates of the quantities of materials and waste that would be produced by a new nuclear power plant fleet are currently being studied by the CEA for the 2016-2018 PNGMDR.

DETAILS REGARDING SCENARIO ASSUMPTIONS

TYPES OF NUCLEAR POWER REACTOR

In these scenarios, a distinction is made between four types of nuclear power reactor:

- **Graphite-moderated gas-cooled reactor (GCR):** first-generation reactor. There are nine reactors of this type in France, six belonging to EDF and 3 to the CEA, and they are all now shut down. The dismantling of these reactors generates LLW-LL (low-level long-lived) graphite waste.
- **Pressurised water reactor (PWR):** second-generation reactor. There are 58 reactors of this type currently in operation in France, with an electrical power of 900, 1300 or 1450 MWe depending on the reactor. All the PWRs use uranium oxide fuel (ENU and ERU) or uranium and plutonium mixed oxide fuel (MOX). MOX fuel is currently licensed for use in 24 PWR reactors. Enriched reprocessed uranium (ERU) fuel made from uranium oxide is licensed for use in four reactors.
- **EPR™ (European Pressurised Reactor):** third-generation pressurised water reactor with an electrical power of around 1650 MWe. The first French EPR™ is currently being built at the Flamanville site.
- **Sodium-cooled fast neutron reactor (FNR):** fourth-generation reactor, for which the French industrial demonstrator, known as ASTRID, is currently at the preliminary design stage. This type of reactor may use uranium and plutonium mixed oxide fuel and allow multi-recycling.

REACTOR OPERATING PERIOD

The scenarios assume different operating periods for current nuclear power reactors. These assumptions do not anticipate any decisions taken by the ASN following the safety reviews for these reactors performed during their ten-yearly reviews.

TOTAL NUCLEAR POWER PRODUCTION CAPACITY

In accordance with the French law on energy transition for green growth, the holders of radioactive materials and waste have assumed a total nuclear power production capacity that does not exceed 63.2 GWe. At the end of 2016, the installed capacity of the 58 reactors in operation was 63.13 GWe.

REPROCESSING OF SPENT FUEL

French energy policy makes provision for fuel to be reprocessed after use. The reprocessing operations that currently take place at the Orano (formerly Areva) plant at La Hague make it possible to extract around 96% recoverable materials (plutonium and uranium) and 4% radioactive waste from spent fuel. The plutonium extracted is used to manufacture MOX fuel (uranium and plutonium mixed oxide fuel). Mono-recycling involves recycling plutonium once in MOX fuel, which is then stored after use pending recovery at a later date. Irradiated MOX fuel unloaded from the PWRs still contains a significant quantity of plutonium. Multi-recycling involves reprocessing this irradiated fuel to extract the recoverable materials then using it to manufacture new fuel several times over.

PRESENTATION OF SCENARIOS

For the nuclear power sector, the key assumptions made are given below for each of the scenarios. The quantities of radioactive materials and waste are estimated based on assumptions made at the end of 2016 for scenarios SR1, SR3 and SNR, and at the end of 2013 for scenario SR2. The estimates take into account the radioactive materials and waste from basic nuclear installations, defence-related installations and "nuclear" installations classified on environmental protection grounds (ICPE), including from non-nuclear-power sectors.

SR1: RENEWAL OF NUCLEAR POWER PLANT FLEET WITH EPR™ THEN FNR REACTORS

Scenario SR1 assumes that nuclear power production continues with the deployment of EPR™ then FNR reactors, and that spent fuel continues to be reprocessed (the current strategy is maintained).

The key assumptions made for this scenario are:

- the continuation of nuclear power production;
- an operating period of between 50 and 60 years for the reactors in the current nuclear power plant fleet;
- the gradual replacement of the reactors in the current nuclear power plant fleet with EPR™ reactors, then with FNR reactors, which could eventually comprise the entire future fleet;
- the reprocessing of all spent fuel. By convention, this assumes that:
 - there are fuel reprocessing plants available to perform these operations,
 - materials separated during fuel reprocessing are recycled in current PWR reactors and EPR™ reactors (mono-recycling), then in FNR reactors allowing multi-recycling.

► ESTIMATE OF QUANTITIES OF RADIOACTIVE WASTE AT END OF FACILITY LIFE (m³)

Radioactive waste at the end of facility life, in m³	
HLW	12,000
ILW-LL	72,000
LLW-LL	190,000
LILW-SL	2,000,000
VLLW	2,300,000

The estimates do not take into account the radioactive materials and waste that would be generated by the operation of new reactors replacing the reactors in the current fleet, as they had not been licensed as of the end of 2016.

The assumptions regarding the reprocessing of all spent fuel and the deployment of EPR™ then FNR reactors involve assuming that all the materials are recovered. No materials are therefore reclassified as waste at the end of facility life. The spent fuel, depleted uranium and RepU generated by the current fleet and which would be consumed by a future fleet are not considered waste at the end of facility life and are therefore not quantified.

The materials from reprocessing part of the spent fuel produced by the current nuclear power plant fleet will be used in a future fleet of EPR™ then FNR reactors. The quantities of spent fuel produced by the current fleet, the material from which will be used in a future fleet after reprocessing, are 20,000 tHM for ENU fuel, 3,700 tHM for ERU fuel and 5,200 tHM for MOX fuel.

SR2: RENEWAL OF NUCLEAR POWER PLANT FLEET WITH EPR™ AND FNR REACTORS, VERSION B

Scenario SR2 uses the assumptions and data from the scenario in the 2015 edition of the National Inventory. As for scenario SR1, it is based on nuclear power production continuing with the deployment of EPR™ then FNR reactors, and the current spent fuel reprocessing strategy being maintained.

The key assumptions made for this scenario are:

- the continuation of nuclear power production;
- a uniform 50-year operating period for all reactors;
- the gradual replacement of the reactors in the current nuclear power plant fleet with EPR™ reactors, then with FNR reactors, which could eventually comprise the entire future fleet;
- the reprocessing of all spent fuel. By convention, this assumes that:
 - there are fuel reprocessing plants available to perform these operations,
 - materials separated during fuel reprocessing are recycled in current PWR reactors and EPR™ reactors (mono-recycling), then in FNR reactors allowing multi-recycling.

► ESTIMATE OF QUANTITIES OF RADIOACTIVE WASTE AT END OF FACILITY LIFE (m³)

Radioactive waste at the end of facility life, in m³	
HLW	10,000
ILW-LL	72,000
LLW-LL	190,000
LILW-SL	1,900,000
VLLW	2,200,000

The estimates do not take into account the radioactive materials and waste that would be generated by the operation of new reactors replacing the reactors in the current fleet, as they had not been licensed as of the end of 2016.

The assumptions regarding the reprocessing of all spent fuel and the deployment of EPR™ then FNR reactors involve assuming that all the materials are recovered. No materials are therefore reclassified as waste at the end of facility life. The spent fuel, depleted uranium and RepU generated by the current fleet and which would be consumed by a future fleet are not considered waste at the end of facility life and are therefore not quantified.

SR3: RENEWAL OF NUCLEAR POWER PLANT FLEET WITH EPR™ REACTORS ONLY

Scenario SR3 is based on continued nuclear power production with the deployment of EPR™ reactors only.

The key assumptions made for this scenario are:

- the continuation of nuclear power production;
- an operating period of between 50 and 60 years for the reactors in the current nuclear power plant fleet;
- the gradual replacement of the reactors in the current nuclear power plant fleet with EPR™ reactors only, which could eventually comprise the entire future fleet;
- the reprocessing of spent ENU fuel only, with spent MOX and ERU fuel not being reprocessed. By convention, this assumes that:
 - there are fuel reprocessing plants available to perform these operations,
 - materials separated during ENU fuel reprocessing are recycled in current PWR reactors and EPR™ reactors (mono-recycling).

► ESTIMATE OF QUANTITIES OF RADIOACTIVE WASTE AND RADIOACTIVE MATERIALS THAT MAY BE RECLASSIFIED AS WASTE AT THE END OF FACILITY LIFE

Radioactive waste at the end of facility life, in m ³		
HLW		9,400
ILW-LL		70,000
LLW-LL		190,000
LILW-SL		2,000,000
VLLW		2,300,000
Radioactive materials that may be reclassified as waste at the end of facility life, in tHM		
Natural uranium	Mined natural uranium, in all its physicochemical forms	-
	Enriched natural uranium, in all its physicochemical forms	-
	Depleted uranium, in all its physicochemical forms ¹	470,000
Uranium from spent fuel reprocessing	Uranium from the reprocessing of spent fuel, in all its physicochemical forms	-
Uranium oxide fuel from nuclear power reactors (ENU, ERU)	Spent fuel	3,700
Uranium and plutonium mixed oxide fuel from nuclear power reactors (MOX, FNR)	Spent fuel	5,400
	Non-irradiated fuel scrap	290
Research reactor fuel	Other spent civil fuel	5
Non-irradiated separated plutonium, in all its physicochemical forms		-
Other materials		70

The estimates do not take into account the radioactive materials and waste that would be generated by the operation of new reactors replacing the reactors in the current fleet, as they had not been licensed as of the end of 2016.

At the end of facility life, certain materials are no longer recoverable – they may then be reclassified as radioactive waste and sent for disposal. Spent MOX and ERU fuel is not reprocessed. It is considered as waste and assumed to be disposed of as it is.

¹ All or part of the depleted uranium can be recycled in ENU fuel, depending on market conditions.

SNR: NON-RENEWAL OF THE NUCLEAR POWER PLANT FLEET

This scenario assumes that the existing fleet is not renewed, leading to the immediate cancellation of the nuclear programme.

The key assumptions made for this scenario are:

- the shutdown of nuclear power production;
- an operating life of 40 years for the 58 PWR reactors and 60 years for the Flamanville EPR™;
- the early shutdown of spent ENU fuel reprocessing to avoid holding separated plutonium. Spent MOX and ERU fuel is not reprocessed.

► ESTIMATE OF QUANTITIES OF RADIOACTIVE WASTE AND RADIOACTIVE MATERIALS THAT MAY BE RECLASSIFIED AS WASTE AT THE END OF FACILITY LIFE

Radioactive waste at the end of facility life, in m ³		
HLW		4,200
ILW-LL		61,000
LLW-LL		190,000
LILW-SL		1,800,000
VLLW		2,100,000
Radioactive materials that may be reclassified as waste at the end of facility life, in tHM		
Natural uranium	Mined natural uranium, in all its physicochemical forms ¹	17
	Enriched natural uranium, in all its physicochemical forms ¹	7
	Depleted uranium, in all its physicochemical forms ²	400,000
Uranium from spent fuel reprocessing	Uranium from the reprocessing of spent fuel, in all its physicochemical forms ²	34,000
Uranium oxide fuel from nuclear power reactors (ENU, ERU)	Spent fuel	25,000
Uranium and plutonium mixed oxide fuel from nuclear power reactors (MOX, FNR)	Spent fuel	3,300
	Non-irradiated fuel scrap	290
Research reactor fuel	Other spent civil fuel	54
Non-irradiated separated plutonium, in all its physicochemical forms ¹		2
Other materials		70

At the end of facility life, certain materials are no longer recoverable – they may then be reclassified as radioactive waste and sent for disposal. Residual ENU fuel that has not been reprocessed at the end of the reactor operating period, as well as ERU and MOX fuel that has not been reprocessed, is considered to be waste and assumed to be stored as it is.

1 These materials are potentially recoverable, in the current fleet, before its shutdown.

2 These materials are potentially recoverable in France or abroad.

SUMMARY OF SCENARIOS

► SUMMARY OF ESTIMATES OF WASTE AND MATERIALS THAT MAY BE RECLASSIFIED AS WASTE AT THE END OF FACILITY LIFE

Depending on their classification, materials are allocated to a waste category. This does not, particularly in the case of uranium, indicate the management solution that will be selected. As part of the 2016-2018 PNGMDR, studies are under way regarding management options should depleted uranium and RepU be reclassified as waste in the future.

		SR1	SR2 ¹	SR3	SNR
Continuation or shutdown of nuclear power production		Continuation (total operating period of between 50 and 60 years)	Continuation (total operating period of 50 years)	Continuation (total operating period of between 50 and 60 years)	Shutdown after 40 years (except EPR™ after 60 years)
Type of reactor deployed in future fleet		EPR then FNR	EPR then FNR	EPR	/
Reprocessing of spent fuel		All: ENU, ERU, MOX and FNR	All: ENU, ERU, MOX and FNR	ENU only	Early shutdown of ENU reprocessing
Reclassification of spent fuel and uranium as waste		None	None	ERU, MOX, FNR and depleted uranium	All spent fuel, depleted uranium and RepU
HLW	Spent uranium oxide fuel from nuclear power reactors (ENU, ERU)	-	-	3,700 tHM	25,000 tHM
	Spent uranium and plutonium mixed oxide fuel from nuclear power reactors (MOX, FNR)	-	-	5,400 tHM	3,300 tHM
	Vitrified waste	12,000 m ³	10,000 m ³	9,400 m ³	4,200 m ³
ILW-LL		72,000 m ³	72,000 m ³	70,000 m ³	61,000 m ³
LLW-LL	Waste ^{2,3}	190,000 m ³	190,000 m ³	190,000 m ³	190,000 m ³
	Depleted uranium, in all its physicochemical forms	-	-	470,000 tHM	400,000 tHM
	Uranium from the reprocessing of spent fuel, in all its physicochemical forms	-	-	-	34,000 tHM
LILW-SL		2,000,000 m ³	1,900,000 m ³	2,000,000 m ³	1,800,000 m ³
VLLW ⁴		2,300,000 m ³	2,200,000 m ³	2,300,000 m ³	2,100,000 m ³

Note

Waste quantities are expressed in "conditioned equivalent volume".

Material quantities are expressed in "tonnes of heavy metal".

Fuel quantities can also be expressed in "number of assemblies" and would represent around 20,000 assemblies at the end of facility life in scenario SR3 or 57,000 assemblies at the end of facility life in scenario SNR.

¹ The data for SR2 was reported at the end of 2013.

² Does not take into account the LLW-LL RTCU waste that will be produced from 2019 onwards.

³ Value re-evaluated since the 2015 edition of the National Inventory.

⁴ Takes into account the VLLW waste from the thermal treatment of nitrated effluents at Malvésí.

NOTE ON COMPARING THE DIFFERENT SCENARIOS

Certain assumptions made in scenario SR2 have changed since the 2015 edition, which may make it difficult to compare scenarios SR1, SR3 and SNR to scenario SR2.

HLW	<ul style="list-style-type: none"> ■ The quantity of vitrified waste produced is linked to the operating periods of the reactors in the current nuclear power plant fleet. ■ Whether or not the current nuclear power plant fleet is renewed, and the type of reactor that would replace the current reactors if it is renewed, are factors that have an impact on the quantity and type of waste at the end of fleet life: vitrified waste only in scenarios SR1 and SR2, or vitrified waste and spent fuel in scenarios SR3 and SNR.
ILW-LL	<ul style="list-style-type: none"> ■ The quantity of waste produced is linked to the operating periods of the reactors in the current nuclear power plant fleet. ■ The incorporation of operating experience feedback and new industrial targets has led to the re-evaluation of the ILW-LL waste forecasts in scenarios SR1, SR3 and SNR. ■ Whether or not the current nuclear power plant fleet is renewed, and the type of reactor that would replace the current reactors if it is renewed, are factors that have an impact on the quantity and type of waste at the end of fleet life.
LLW-LL	<ul style="list-style-type: none"> ■ The quantity of waste at the end of facility life is not dependent on the scenarios. ■ In scenarios SR1 and SR2, all the depleted uranium is assumed to be recoverable in the form of MOX fuel, in contrast to scenarios SR3 and SNR, in which part of it could be reclassified as radioactive waste. The continuation of nuclear power production in scenario SR3, which means that uranium enrichment operations also continue, increases the depleted uranium inventory. The shutdown of nuclear power production assumed in scenario SNR, leads to the shutdown of enrichment and MOX fuel manufacture operations, which results in the non-recovery of inventory. Depleted uranium, due to its characteristics, could be similar to LLW-LL waste. ■ In scenarios SR1, SR2 and SR3, uranium from the reprocessing of spent fuel (RepU) is assumed to be recoverable as it can be recycled in ERU fuel. The cancellation of the nuclear programme results in the definitive shutdown of RepU recycling, resulting in the non-recovery of RepU inventory. Reprocessed uranium, due to its characteristics, could be similar to LLW-LL waste.
LILW-SL VLLW	<ul style="list-style-type: none"> ■ The quantity of waste produced is directly linked to the operating periods of the reactors in the current nuclear power plant fleet. The extension of the operating period will increase the quantity of operating waste generated.

ESTIMATE OF QUANTITIES OF MATERIALS AND WASTE AT INTERMEDIATE DATES

The regulations require holders to estimate the quantities of radioactive materials and waste at specific dates. For the first two renewal scenarios, these estimates are performed for the following dates: end of 2030 and end of 2040 for scenario SR1; end of 2020 and end of 2030 for scenario SR2.

► ESTIMATES OF QUANTITIES OF FRENCH WASTE AT INTERMEDIATE DATES FOR SCENARIOS SR1 AND SR2 (m³)

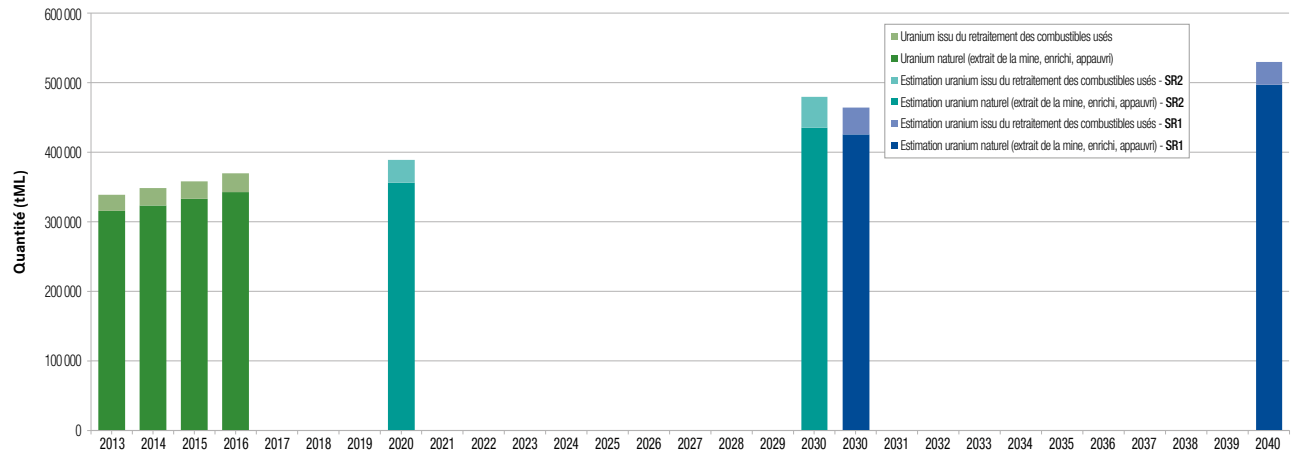


The changes over time can be explained by:

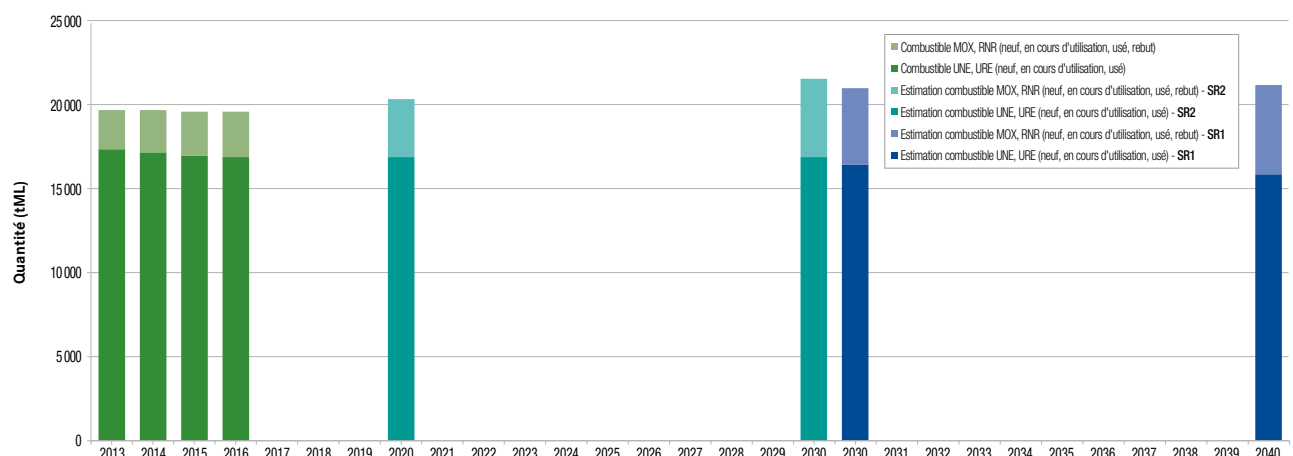
- the ongoing production of HLW, ILW-LL, LILW-SL and VLLW waste according to different operating period assumptions;
- for ILW-LL waste, the re-evaluation of the waste forecasts in scenario SR1 due to the incorporation of operating experience feedback and new industrial targets;
- the deferment of the dismantling of GCR reactor tanks for scenario SR1, and therefore delayed production of LLW-LL graphite waste;
- the deferment of the production of VLLW waste.

► ESTIMATES OF QUANTITIES OF FRENCH MATERIALS AT INTERMEDIATE DATES FOR SCENARIOS SR1 AND SR2

Natural uranium (mined, enriched, depleted) and uranium from spent fuel reprocessing (RepU)



Uranium oxide fuel from nuclear power reactors (ENU, ERU) and uranium and plutonium mixed oxide fuel from new nuclear power reactors (MOX, FNR), in use and spent, scrap¹



The changes over time can be explained as follows:

- The increase in the quantity of natural uranium is chiefly due to the production of depleted uranium from the enrichment of natural uranium, but does not anticipate the effective recovery of the depleted uranium over this period.
- In scenario SR1, the reduction in the quantity of uranium from the reprocessing of spent fuel (RepU) is due to it being recycled in uranium oxide fuel (ERU).
- The stability of the quantity of uranium oxide fuel (ENU, ERU) from nuclear power reactors is linked to the reprocessing of ENU.
- The increase in the quantity of uranium and plutonium mixed oxide fuel from nuclear power reactors is due to the increase in MOX fuel inventory pending recovery at a later date.

¹ The second Superphénix core is not taken into account here.



Où sont-ils ?

Combien
y en a-t-il
aujourd'hui ?

Combien
y en aura-t-il
demain ?

All the data on radioactive materials
and waste is available at
inventaire.andra.fr