ESSENTIALS

National Inventory of Radioactive Materials and Waste

2022

ANDRA
Agence nationale pour la gestion des déchets radioactifs

MINISTÈRE
DE LA TRANSITION
ÉCOLOGIQUE
Liberté
Égalité
Fraternité

Every five years*, Andra publishes a new edition of the **National Inventory of Radioactive Materials and Waste**. An annual companion publication named **Essentials** presents any changes to the volumes of radioactive materials and waste produced in France.

Essentials 2022 provides an update on the stocks of radioactive materials and waste present on French soil on 31 December 2020.

Andra also produces "forecast inventories" accompanying each new edition of the **National Inventory**, the next of which is scheduled for 2023. These forecasts contain estimates of material and waste quantities based on a number of contrasting scenarios modelling the future of France's nuclear facilities and long-term energy policy. The forecast inventories from the last edition of the **National Inventory** (2018) are included in **Essentials** 2022.

The **National Inventory** is a valuable tool for guiding French policy on management of radioactive materials and waste.

All **National Inventory** data is available on the dedicated website at www.inventaire.andra.fr and as open data at data.gouv.fr.

* Under the terms of Article L542-12 of the French Environment Code, as amended by Act 2020-1225 of 7 December 2020.

CONTENTS

Figures stated in this document have been rounded. They are based on the declarations made by holders of radioactive materials and waste, and reflect the situation on 31 December 2020. Radiological inventories and forecasts are taken from the 2018 edition of the National Inventory.

1 RADIOACTIVE MATERIALS AND WASTE AND RELATED MANAGEMENT METHODS

RADIOACTIVITY-USING SECTORS

Various economic sectors employ radioactive materials. They also produce radioactive waste. As radioactivity can present a risk to health and the environment, radioactive materials and waste are subject to specific management requirements.

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

Radioactivity is a natural phenomenon that has existed since the dawn of the universe when atoms were formed. The term describes a phenomenon whereby certain atoms – known as radionuclides – release energy as they decay, in the form of radiation and/or particles. Radioactivity can also be created artificially through human activities, using a particle accelerator or a nuclear reactor to create radioactive nuclei not naturally present in the environment.

NUCLEAR POWER INDUSTRY
Nuclear power plants, but also facilities dedicated to producing nuclear fuel (via uranium ore mining and processing, chemical conversion and enrichment of uranium concentrate), reprocessing spent fuel and recycling a portion of the materials recovered from it.

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, etc.

RESEARCH
Research activities for civil nuclear applications, medical science, nuclear and particle physics, agronomics, chemistry and biology, among others.

DEFENCE
Nuclear deterrence force, including nuclear propulsion for certain ships and submarines, as well as related research and activities relating to the armed forces.

HEALTHCARE
Diagnostic and therapeutic activities (e.g. scintigraphy and radiotherapy).

RADIOACTIVE MATERIALS AND RELATED 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 (cf. Article L. 542-1-1 of the French Environmental Code).

NATURAL URANIUM

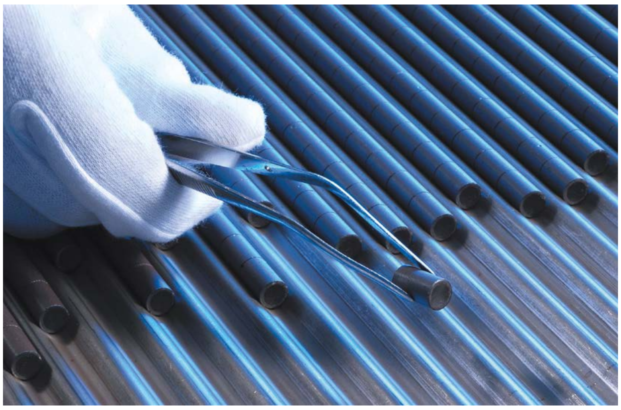
Yellowcake

- **Mined natural uranium**: uranium is a naturally-occurring radioactive metal found as an ore in certain rocks. 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 is sourced from abroad.
- **Enriched natural uranium**, obtained by increasing the uranium-235 concentration of natural uranium, is used to manufacture fuel for nuclear reactors.
- **Depleted uranium**, obtained during the natural uranium enrichment process and transformed into a solid, chemically stable, non-combustible, insoluble and non-corrosive material in the form of a black powder. This material is used to manufacture uranium and plutonium mixed oxide fuel (MOX).

URANIUM FROM SPENT FUEL REPROCESSING

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

NUCLEAR FUEL



Fuel pellets

Nuclear fuel is mainly used to generate electricity at nuclear power plants.

The term covers:

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

It may also refer to:

- **fuel** used in research reactors;
- **fuel for defence purposes**, used for deterrence activities and in nuclear propulsion reactors in ships and submarines;
- **fast neutron reactor (FNR) fuel made from mixed uranium and plutonium oxide**, for the Phénix and Superphénix reactors, now permanently decommissioned and no longer used.

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

PLUTONIUM

Plutonium is an artificial radioactive element generated by the operation of nuclear reactors. Like uranium, it is 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 (which occur naturally in the Earth's crust) are extracted from ores such as monazite and used in numerous applications (e.g. electronic equipment, automotive catalytic converters, etc.).

The extraction process produces the following materials:

- **thorium**, a by-product of concentration, which is stored pending possible future use;
- **materials in suspension**, obtained by processing and neutralising chemical effluent, comprising traces of rare-earth residue that can be reused.

RADIOACTIVE MATERIAL MANAGEMENT METHODS

Radioactive materials are stored in facilities suited to their characteristics until they can be used or reused. For some materials, such as plutonium from reprocessing spent uranium oxide fuel, a process enabling their reuse in industry has already been in place for more than thirty years.

For other materials, reuse is only a potential future option – the National Radioactive Materials and Waste Management Plan (PNGMDR) requires owners of radioactive materials and waste to regularly check whether stored materials are recoverable.

Spent fuel storage pool at the Orano reprocessing plant in La Hague

Storage of radioactive materials or waste consists in temporarily placing these radioactive substances in a surface or near-surface facility specially designed for the purpose, with the intention of retrieving them at a later date.

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

RADIOACTIVE WASTE AND RELATED 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 Environmental Code).

In general, radioactive waste contains a mix of radionuclides (i.e. radioactive isotopes: caesium, cobalt, strontium, etc.). Depending on the waste's composition, its radioactivity may vary in intensity and persist for different periods of time. Waste is classified in six categories.

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

RADIOACTIVE WASTE CATEGORIES AND RELATED MANAGEMENT SOLUTIONS

Radioactive half-life* / Activity**	Very short-lived (VSL) (half-life < 100 days)	Mainly short-lived (SL) (half-life ≤ 31 years)	Mainly long-lived (LL) (half-life > 31 years)
Very low-level waste (VLLW) < 100 Bq/g	VSL Management through radioactive decay	VLLW Surface disposal (Industrial facility for grouping, storage, and disposal)	
Low-level waste (LLW) between a few hundred Bq/g and one million Bq/g		LILW-SL Surface disposal facility (Aube and Manche disposal facilities)	LLW-LL Near-surface disposal facility under study
Intermediate-level waste (ILW) approx. one million to one billion Bq/g			ILW-LL Deep geological disposal facility under development (Cigeo project)
High-level waste (HLW) approx. several billion Bq/g	Not applicable		HLW

*Half-life of the radioactive elements (radionuclides) contained in the waste
**Activity level of the radioactive waste

Waste may sometimes be classified in a particular category but managed using an alternative management solution due to other characteristics, such as its chemical composition or physical properties.

Radioactive half-life

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

- very short-lived waste, which contains radionuclides with a half-life shorter than 100 days. This waste 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 waste, the radioactivity in which derives mainly from radionuclides with a half-life less than or equal to 31 years;
- long-lived waste, which contains a significant quantity of radionuclides with a half-life exceeding 31 years.

Activity level

The "activity" reflects the number of disintegrations of nuclei produced per second (and hence the radiation per second). It is expressed in becquerels: 1 becquerel (Bq) is equal to one disintegration per second.

Accordingly, radioactive waste is said to be:

- very low-level, when its activity level is less than 100 becquerels per gramme;
- ow-level, when its activity level is between a few hundred becquerels per gramme and one million becquerels per gramme;
- intermediate-level, when its activity level is between one million and one billion becquerels per gramme;
- high-level, when its activity level is around several billion becquerels per gramme.

DESCRIPTION OF RADIOACTIVE WASTE CATEGORIES

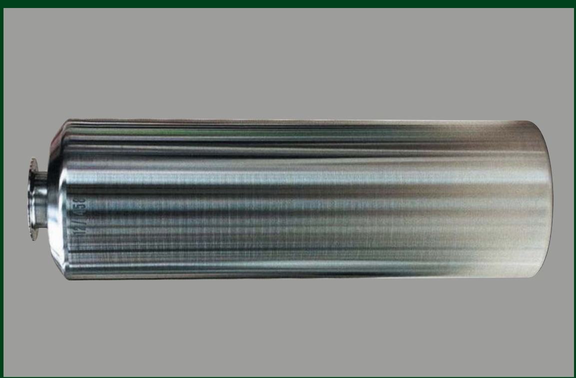
HLW HIGH-LEVEL WASTE

High: several billion Bq/g

Up to very long (up to several hundreds of thousands of years)

Deep geological disposal under development[1]

This waste mainly comes from the reprocessing of spent fuel[2] (after use in a nuclear reactor). It is made up of highly radioactive residue from the chemical dissolution of spent fuel. This waste is encapsulated in glass, then conditioned in stainless steel containers.



HLW waste package

ILW-LL INTERMEDIATE-LEVEL LONG-LIVED WASTE

Intermediate: 1 million to 1 billion Bq/g

Long to very long (up to several hundreds of thousands of years)

Deep geological disposal under development[1]

Most of this waste consists of metal hulls and end caps from inside which fuel is removed for reprocessing[2]; technological waste from the use and maintenance of nuclear facilities, waste from the treatment of liquid effluent (bituminised sludge) and activated waste from inside nuclear reactors make up the remainder.

Hulls from the zirconium alloy cladding that covers fuel pellets

LLW-LL LOW-LEVEL LONG-LIVED WASTE

Low: a few tens to several hundred thousand 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 earliest 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 packages of legacy waste conditioned in bitumen, uranium conversion treatment residue from the Orano Malvési plant (see page 16), and operating waste from the La Hague reprocessing plant.

1 Cigeo project.

2 Reprocessing 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 reprocessing sites pending disposal.

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

Low to intermediate: a few hundreds to 1 million Bq/g

Short (up to around 300 years)

Existing surface disposal[1]

The main sources of this waste are the operation (processing of liquid effluent or filtration of gaseous effluent, etc.), maintenance (clothing, tools, gloves, filters, etc.) and dismantling of nuclear plants, fuel cycle facilities and research centres. A small portion may also come from medical research activities.

Waste from the use of radioactive products in laboratories

VLLW VERY LOW-LEVEL WASTE

Very low: less than 100 Bq/g

Not a determining factor[2]

Existing surface disposal[3]

This mainly comes from the operation, maintenance and dismantling of nuclear plants, fuel cycle facilities and research centres.
VLLW usually consists of inert waste (concrete, rubble, earth, etc.) or metal and plastic waste.

Rubble waste from dismantling

VSL VERY SHORT-LIVED WASTE

Very low to intermediate

Very short (up to around three years)

Management through decay

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

Decay tanks

Activity level. Time required for the radioactivity to decay (to a level that presents no risks to human health or the environment). This time 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 Aube.

RADIOACTIVE WASTE MANAGEMENT METHODS

To contain and isolate waste from humans and the environment, France has decided to manage it in dedicated disposal facilities, where necessary after a prior storage period.

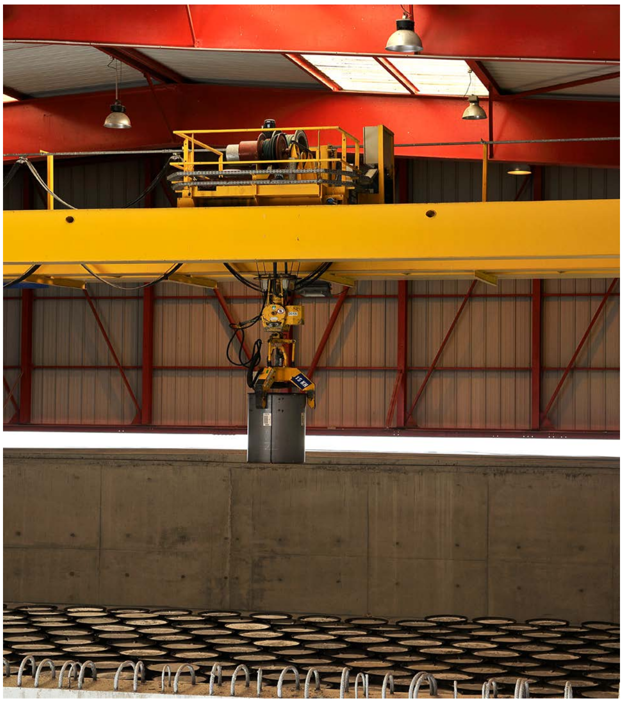
Three types of disposal facility already exist or are currently under development. They are engineered for the radioactivity level and longevity of the waste placed in them:

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

The latter two types of disposal facility are being developed by Andra, in accordance with the provisions of the Act of 28 June 2006.

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

Radioactive waste disposal consists in placing these substances in a facility specially designed to hold them on a potentially permanent basis [...], with no intention of retrieving them at a later date.
Article L.542-1-1 of the French Environmental Code



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

In the case of very short-lived waste (VSLW), radioactivity decreases significantly within a few months, or even a few days or hours. Such waste is therefore stored on site while this radioactive decay takes place, before being disposed of via the conventional waste management solution best suited to its physical, chemical and biological characteristics.

Lastly, certain items of radioactive waste cannot yet be treated and conditioned in a way that makes them suitable for an identified management solution, generally due to their special physical or chemical characteristics. Such waste is conventionally referred to as 'waste without a specific disposal solution' (DSF). After being processed, conditioned or characterised, where appropriate, DSF is submitted to the appropriate management process.

REVIEW OF RADIOACTIVE MATERIAL AND WASTE PRODUCTION BY THE FRENCH NUCLEAR POWER SECTOR

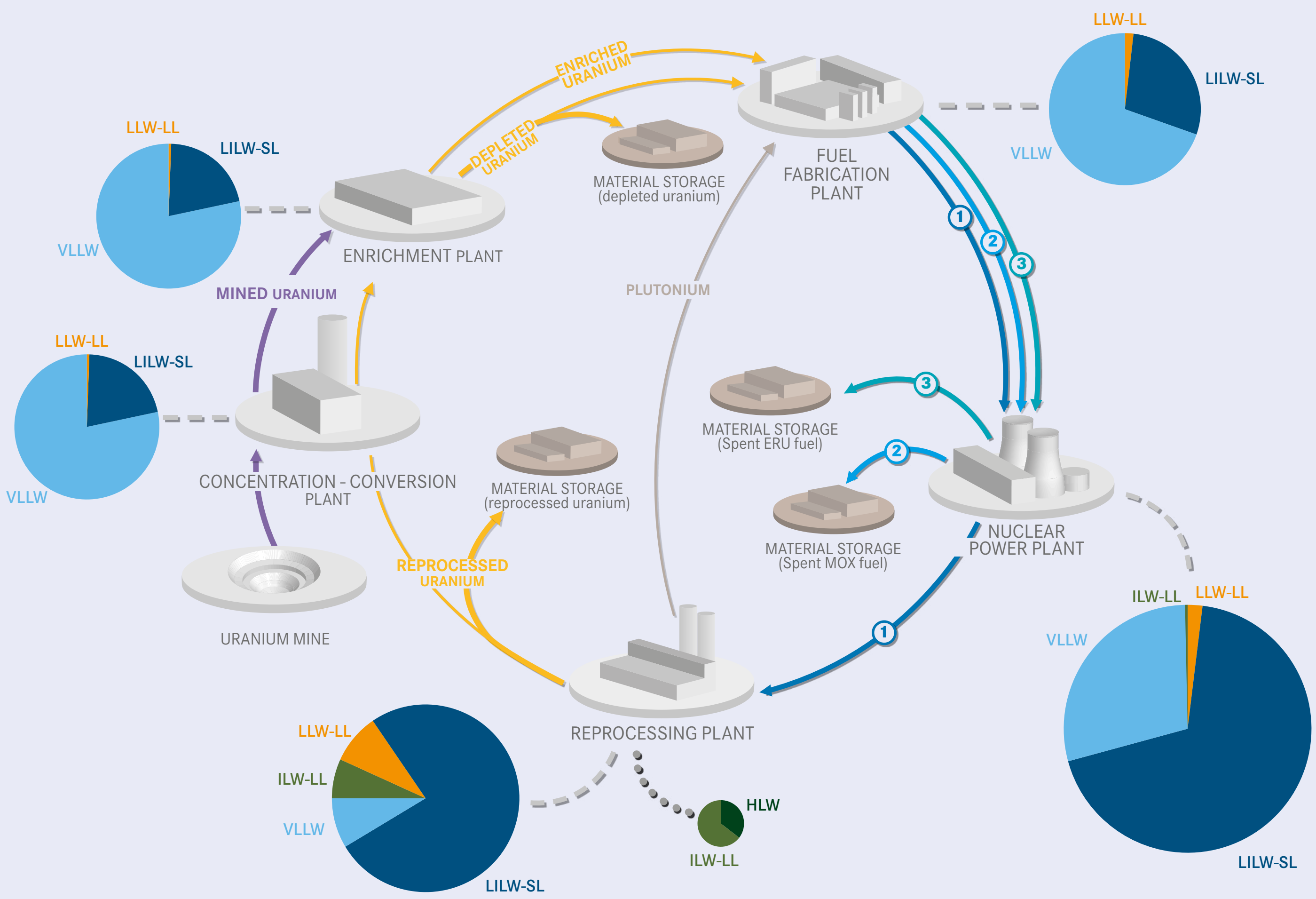
Most radioactive materials and waste produced by the nuclear power sector result from running the facilities that manufacture, use and then reprocess nuclear fuel.

This includes both the operation of the facility and its dismantling.

Most of the waste produced by the operation of these plants is taken to Andra's industrial facilities in the Aube (Cires and CSA). Smaller quantities of intermediate-level long-lived waste (ILW-LL) and high-level waste (HLW) are also produced, and are stored at production sites pending construction of the Cigeo disposal facility, which will ultimately receive the waste. The nuclear power sector generates a small amount of low-level long-lived waste (LLW-LL), for which a repository is also under development.

Dismantling nuclear installations also produces waste, the vast majority of which is very low-level waste (VLLW).

Radioactive materials are currently either recovered or stored pending future reuse. For example, it may be possible to recover reprocessed uranium (RepU) for use in nuclear power reactors, in the form of enriched reprocessed uranium (ERU). Research is being conducted on a cycle featuring sodium-cooled fast reactors which, if the choice to develop a fleet with such facilities is made, should in the future improve material recycling performance, especially for materials obtained by reprocessing 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 recycled uranium oxide fuel (ERU)
Operating and dismantling waste - Inventory at the end of 2020
Residual waste after reprocessing spent fuel - Inventory at the end of 2020

2
INVENTORY OF RADIOACTIVE MATERIALS AT END OF 2020

MATERIALS RECORDED

Andra performs an annual inventory of all radioactive materials present on French territory on 31 December every year, based on information provided by the holders of those materials. These are substances for which later use is planned or envisaged, if necessary after reprocessing, with the exception of sealed sources, which are registered by the French Institute for Radiological Protection and Nuclear Safety (IRSN) in accordance with Article R. 1333-154 of the French Public Health Code.

For fissile materials, the main material holders are organisations involved in the nuclear fuel cycle, all operators of nuclear reactors (including power, defence and research facilities) and chemical industry stakeholders that hold radioactive materials as part of their activities (e.g. mining rare-earth metals).

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. These foreign materials are to be sent back to their country of origin.

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 materials, except in the case of fuel for defence purposes, for which quantities are stated in tonnes of assemblies (t).

Uranium hexafluoride crystals

INVENTORY OF RADIOACTIVE MATERIALS

The table below shows the inventory of radioactive materials at the end of 2020, the changes compared with the previous year, and the share of materials belonging to foreign countries (foreign materials are to be sent back to their country of origin).

INVENTORY OF RADIOACTIVE MATERIALS (IN tML, EXCEPT SPENT FUEL FOR DEFENCE PURPOSES, WHICH IS EXPRESSED IN TONNES OF ASSEMBLIES)

Material category		End of 2020	2019-2020 YoY change	Foreign share
Natural uranium	mined	39,800	+1,700	
	enriched	3,390	-50	
	depleted	324,000	+2,500	
Uranium from spent fuel reprocessing[1]	enriched	0	-	
	reprocessed	34,100	+1,400	8%
Uranium oxide fuel (ENU, ERU)	before use	611	+192	
	in use	4,070	-90	
	spent	11,700	-118	negligible
	scrap	0	-	
Mixed oxide fuel (MOX, FNR)	before use	27	+11	
	in use	323	-25	
	spent	2,350	+80	
	scrap[2]	315	+16	
Research reactor fuel	before use	0.04	+0.03	
	in use	1	-	
	spent	60	-	2%
Plutonium		60	+2	24%
Thorium		8,564	-5	
Materials in suspension		5	-	
Other materials[3]		70	-	
National defence fuels		198 tonnes	-	

Changes were calculated based on the exact figures, then rounded.

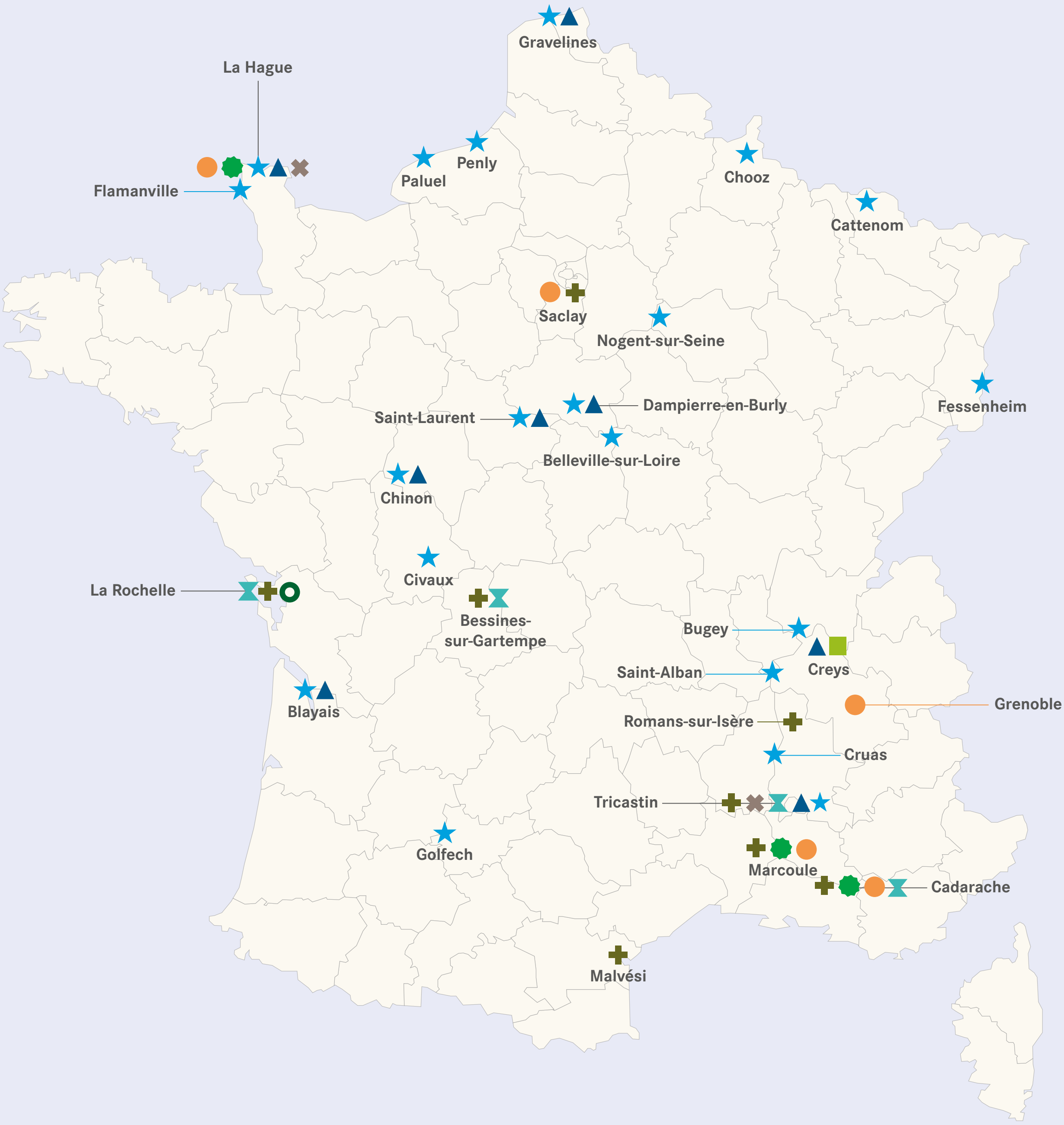
In the current nuclear power generation framework, radioactive materials are used as fuel, processed and/or stored (pending recovery). The difference in inventory levels corresponds to a year of operation of the nuclear power plant fleet.

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 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".

LOCATION OF RADIOACTIVE MATERIALS IN FRANCE ON 31/12/2020



- NATURAL URANIUM
- URANIUM FROM SPENT FUEL REPROCESSING
- URANIUM OXIDE FUEL (ENU, ERU)
- MIXED OXIDE FUEL (MOX, FNR)
- RESEARCH REACTOR FUEL
- THORIUM
- MATERIALS IN SUSPENSION
- PLUTONIUM
- OTHER MATERIALS

National defence fuels are not shown on this map. In order to protect information that if disclosed may harm the interests identified in Article L. 124-4 of the French Environment Code, the corresponding material locations cannot be communicated.

3
INVENTORY OF RADIOACTIVE WASTE AT END OF 2020

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

Disposal of LILW-SL waste packages at the Aube Waste Disposal Facility (CSA)

WASTE ALREADY DISPOSED OF OR DUE TO BE MANAGED BY ANDRA

Stated waste volumes are those 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: the “conditioned equivalent volume”.

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

In the specific case of the Cigeo geological disposal project (which is designed to receive high-level waste (HLW) and intermediate level long-lived waste (ILW-LL)), additional conditioning, in the form of disposal packages, may be necessary, particularly for handling or retrievability purposes. Only the volume of primary packages is taken into account in this document.

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.

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

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

Category	End of 2020	2019-2020 YoY change
HLW	**4,190**	+100
ILW-LL	**42,900**	+200
LLW-LL	**93,800**	+200
LILW-SL	**971,000**	+9,700
VLLW	**586,000**	+16,000
DSF	**295**	-300
Total	**~ 1,700,000**	+25,900

Changes were calculated based on the exact figures, then rounded.

The differences between the quantity of waste at the end of 2019 and that at the end of 2020 can be accounted for by:

- ongoing waste production for all categories;
- the management of some waste without a specific disposal solution (DSF) through appropriate solutions after processing.

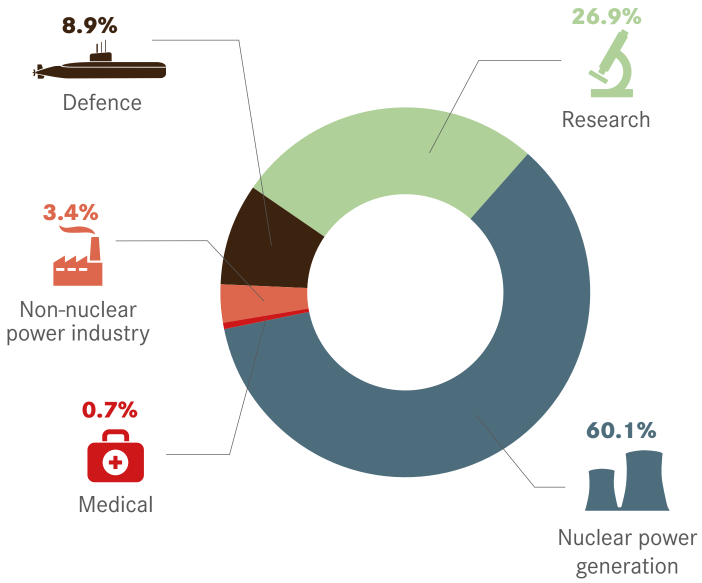
INVENTORY OF VOLUMES (m³) OF WASTE AT PRODUCER/HOLDER SITES AND DISPOSED OF IN ANDRA FACILITIES AT THE END OF 2020

Radioactive waste categories	Total	At producer/ holder sites	Disposed of at Andra facilities	Existing disposal capacity
HLW	**4,190**	4,190	- (1)	-
ILW-LL	**42,900**	42,900	- (1)	-
LLW-LL	**93,800**	93,800	- (1)	-
LILW-SL	**971,000**	90,700	880,000	1,530,000
VLLW	**586,000**	174,000	412,000	650,000
DSF	**295**	295	-	-
Total	**~1,700,000**	~406,000	~1,292,000	
	100%	24%	76%	

LILW-SL and VLLW is stored at production sites pending retrieval, conditioning or removal to Andra disposal facilities.

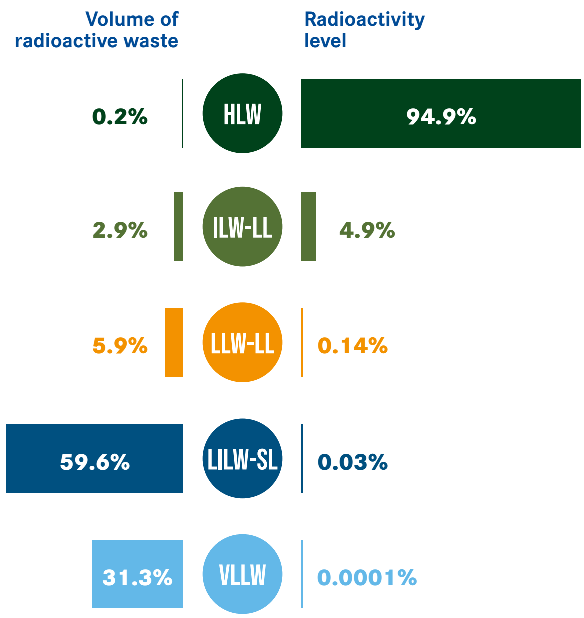
VLLW waste is disposed of at the Cires facility. As of the end of 2020, this facility had reached approximately 63% of its total licensed disposal capacity of 650,000 m³. In its current configuration, Cires will not have sufficient capacity to dispose of the VLLW volumes generated by the dismantling activities scheduled for the coming years. Additional management solutions are therefore currently being studied. The medium-term solution consists in increasing the licensed disposal capacity of Cires, without changing the area of the existing disposal zone and while maintaining its safety level (Acaci project). If approved, this capacity increase will enable Cires to extend its operating life by around a decade, until around 2040.

BREAKDOWN BY ECONOMIC SECTOR OF WASTE VOLUME (CONDITIONED EQUIVALENT VOLUMES) ALREADY DISPOSED OF OR DUE TO BE MANAGED BY ANDRA (AT END OF 2020)



Percentages were calculated based on the exact figures, then rounded.

The breakdown of waste volumes and radioactivity levels shown below is taken from the **2018 edition of the National Inventory** (based on figures at the end of 2016)



1 This waste has not yet been disposed of: the disposal solution for HLW and ILW-LL (Cigeo) is currently under development. The LLW-LL waste disposal solution is also under development. Waste without a specific disposal solution (DSF) will be directed to a management solution after any necessary treatment or characterisation.

VERY SHORT-LIVED WASTE

INVENTORY AND DIFFERENCE IN VOLUMES (m^3) OF VERY-SHORT-LIVED WASTE MANAGED THROUGH DECAY

Category	End of 2020	2019-2020 YoY change
VSL	**2018**	-59

These volumes are not included in the inventory.

SPECIFIC CASE OF WASTE FROM ORANO MALVÉSI

Some of the uranium conversion treatment residue (RTCU) from the Orano Malvési plant is legacy waste. Work is underway to find a safe, long-term management solution at the Malvési site for legacy RTCU waste, given its specific nature (large volumes, etc.). RTCU waste produced after 1 January 2019 was included in the VLLW and LLW-LL management solutions, in accordance with Article 63 of the Order of 23 February 2017 (Decree No. 2017-231).

INVENTORY AND FORECASTS OF VOLUMES OF URANIUM CONVERSION TREATMENT RESIDUE (RTCU) STORED AT THE MALVÉSI SITE (m^3)

	End of 2020	2019-2020 YoY change	End of 2030 (data from 2018 edition)	End of 2040 (data from 2018 edition)
Settling ponds	**73,200**	+7,400	0	0
Legacy RTCU	**282,000**	-	310,000	310,000
Nitrate-containing effluent	**372,000**	-	200,000	110,000

These volumes are not included in the inventory.

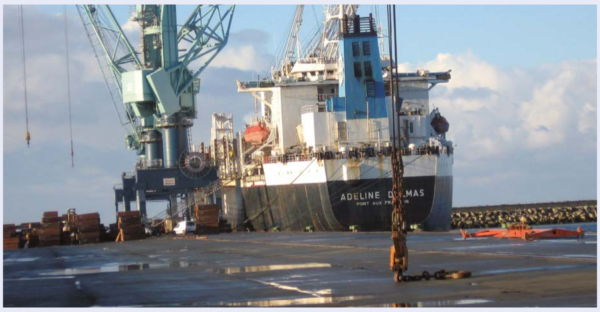
WASTE AND MINING RESIDUE SUBJECT TO SPECIFIC MANAGEMENT METHODS

(This waste is not included in the inventory)

- **Waste disposed of inside or near the perimeter of nuclear facilities or plants.** The corresponding activity is of the order of a few becquerels per gramme (several thousands of tonnes).
- **Residue from processing uranium ores** present on former mining sites. This is long-lived residue with an activity level comparable to that of VLLW (approximately 50 million tonnes).

Former Bellezane mine

- **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 gramme (approximately 3,000 tonnes).
- **Waste containing naturally-occurring radioactive material (NORM) managed through on-site disposal.** This waste is generated by the processing of raw materials that contain naturally-occurring radionuclides but are not used for their radioactive properties. Much of this is comparable to VLLW (around 50 million tonnes).



Residues from treating very slightly radioactive materials were used as backfill at the La Pallice port in La Rochelle.

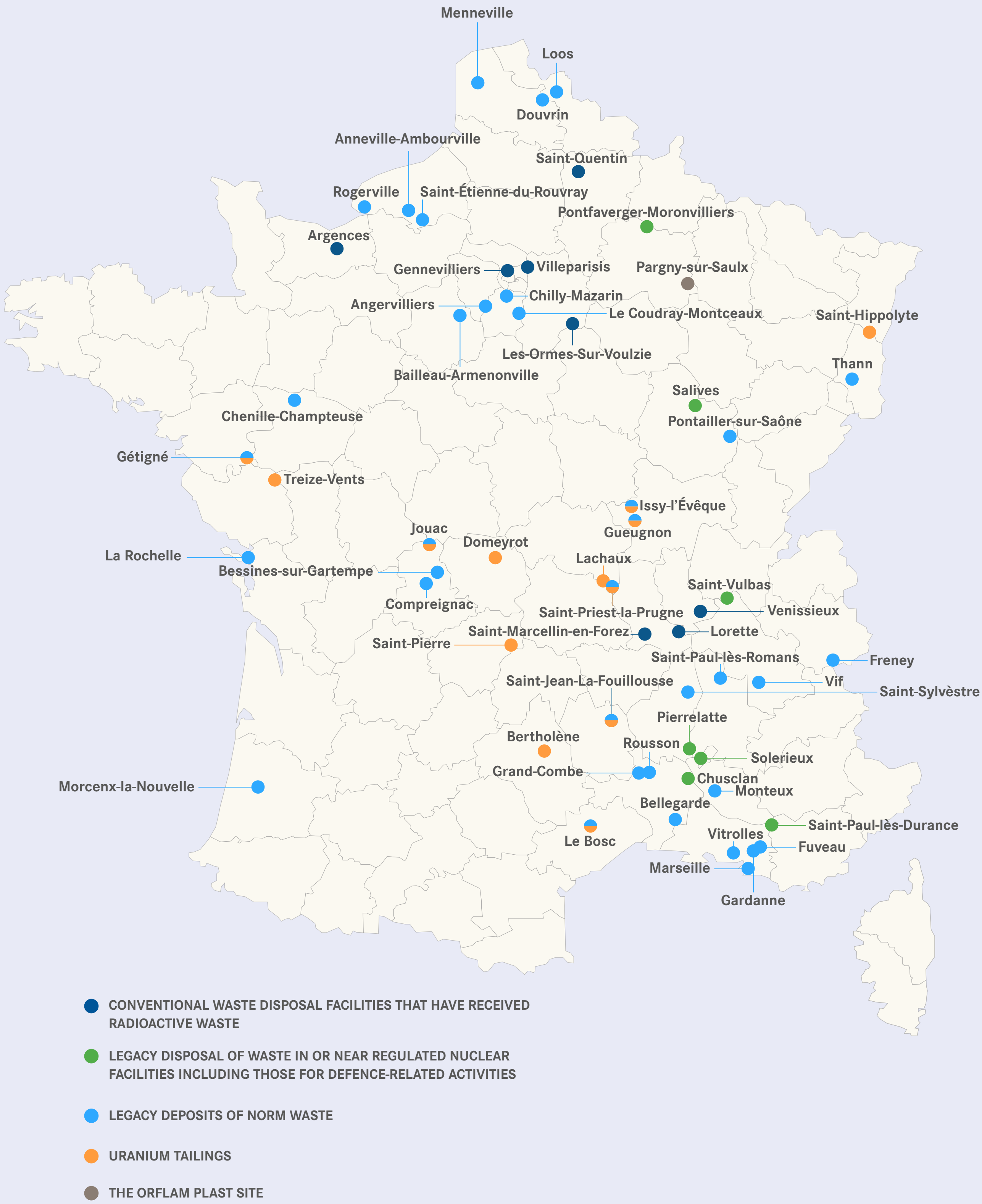
- **Defence disposal sites in French Polynesia.** Between 1966 and 1996, France carried out nuclear experiments in the South Pacific, in French Polynesia. The waste produced by these experiments and on dismantling the associated facilities was disposed of *in situ* in wells or dumped in French territorial waters.
- **Waste dumped at sea.** Dumping radioactive waste at sea was a considered to be a safe management solution 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 in this way by France between 1967 and 1982. A permanent ban on dumping radioactive waste at sea was came into effect in 1993.

Dumping radioactive waste packages

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.

In the 1930s, a monazite processing plant, which would later become the Orflam-Plast plant, was built in Pargny-sur-Saulx to manufacture lighter flints from monazite. The plant operated until 1967, before being permanently decommissioned in 1997. The extraction of monazite, an ore rich in thorium, generated low-level radioactive residue, concentrating the radioactivity initially present in monazite. This residue polluted the site, which was cleaned up at a later date. Much of the waste and earth collected during the cleanup operation was disposed of at Cires. Another fraction, mainly consisting of rubble with very low radioactivity, was contained on site (3,000 m^3).

WASTE AND MINING RESIDUE SUBJECT TO SPECIFIC MANAGEMENT METHODS (IN METROPOLITAN FRANCE)



The quantities declared by radioactive waste producers and holders are available in the Summary of the National Inventory (2018 edition).

4
FORECAST INVENTORIES FROM THE 2018 EDITION

The purpose of the forecast 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 to 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.

At the time of compiling the forecast inventories, France was operating a nuclear power plant fleet of 58 reactors in operation, with one EPR™ reactor under construction, and French energy policy providing for fuel to be reprocessed after use in nuclear power plants.

The forecast inventories were produced considering four different scenarios modelling the evolution of France's 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 use different operating lives in their assumptions for current reactors. They also assume that new reactors will be deployed, with different assumptions made regarding the type of reactor (EPR™ and FNR or EPR™ alone).

The at-term quantities of radioactive waste and materials liable to be reclassified as waste are estimated for each scenario, based on information provided by their holders.

Nuclear power plant cooling towers

The reporting system covers all radioactive substances already produced or scheduled for production by facilities licensed at the end of 2016 (existing fleet).

Materials and waste arising from the operation of new reactors replacing those in the current nuclear power plant fleet are not included[1].

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

The expressions "at-term" and “at the end of facility life” mean after the dismantling of the nuclear facilities licensed at the end of 2016.

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

NOTES REGARDING SCENARIO ASSUMPTIONS

TYPES OF NUCLEAR POWER REACTOR

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

- **Gas-cooled graphite-moderated reactor (GCR):** first-generation reactor. There are nine reactors of this type in France, six belonging to EDF and three to CEA, and they are all now shut down. Dismantling these reactors generates LLW-LL (low-level long-lived) graphite waste.
- **Pressurised water reactor (PWR):** second-generation reactor. At the time of compiling the forecast inventories, 58 reactors of this type were in operation in France, with a rated capacity of 900, 1300 or 1450 MW, depending on the reactor. All PWRs use uranium oxide fuel (ENU and ERU) or uranium and plutonium mixed oxide fuel (MOX). MOX fuel is authorised for use in 24 PWR reactors. Enriched reprocessed uranium (ERU) fuel made from uranium oxide is authorised for use in four reactors.
- **European Pressurized Reactor (EPR™):** third-generation reactor with an electrical output of around 1650 MW. The first French EPR™ is currently under construction at the Flamanville site.
- **Sodium-cooled fast neutron reactor (FNR):** fourth-generation reactor. This type of reactor may be able to use uranium and plutonium mixed oxide fuel and would allow multi-recycling.

REACTOR OPERATING LIFE

The scenarios use different operating lives in their assumptions for current nuclear power reactors. These assumptions do not anticipate any decisions taken by the ASN following the safety reviews of 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, radioactive materials and waste holders assumed that total nuclear power production capacity would 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 operations that currently take place at the Orano La Hague plant to reprocess spent fuel make it possible to extract 96% as recoverable materials (plutonium and uranium), leaving 4% as radioactive waste. The extracted plutonium is used to manufacture MOX fuel (uranium and plutonium mixed oxide fuel). Mono-recycling consists in recycling plutonium once in MOX fuel, which after use is then stored pending recovery at a later date. Irradiated MOX fuel unloaded from PWRs still contains a significant quantity of plutonium. Multi-recycling would consist in reprocessing irradiated fuel to extract recoverable materials and then manufacture new fuel, in a cycle iterated multiple times.

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 the 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 nuclear facilities, defence-related facilities and environmentally regulated facilities (ICPE) with nuclear activities, including from non-nuclear-power sectors.

SR1: RENEWAL OF THE NUCLEAR POWER FLEET WITH EPR™ AND 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 (i.e.e the current strategy is maintained.

The key assumptions made for this scenario are:
- the continuation of nuclear power generation;
- an operating life of between 50 and 60 years for the reactors in the current nuclear power plant fleet;
- phased replacement of the reactors in the current nuclear power plant fleet with EPR™ reactors, then with FNR reactors, which could eventually make up 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;
  - the materials separated during fuel reprocessing are recycled in current PWR reactors and EPR™ reactors (mono-recycling), then in FNR reactors allowing multi-recycling.

ESTIMATED QUANTITIES OF RADIOACTIVE WASTE AT END OF FACILITY LIFE (m^3)

Radioactive waste at end of facility life, in m^3	
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 at the end of 2016.

The assumptions regarding the reprocessing of all spent fuel and the deployment of EPR™ then FNR reactors include the assumption that all the materials are recovered. No materials are therefore reclassified as waste at the end of facility life. Spent fuel, depleted uranium and RepU generated by the current fleet that would be consumed by a future fleet is not considered waste at end of facility life, and is 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 THE NUCLEAR POWER 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. Like 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 generation;
- a 50-year operating life for all reactors;
- phased replacement of the reactors in the current nuclear power plant fleet with EPR™ reactors, then with FNR reactors, which could eventually make up 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;
  - the materials separated during fuel reprocessing are recycled in current PWR reactors and EPR™ reactors (mono-recycling), then in FNR reactors allowing multi-recycling.

ESTIMATED QUANTITIES OF RADIOACTIVE WASTE AT END OF FACILITY LIFE (m^3)

Radioactive waste at end of facility life, in m^3	
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 at the end of 2016.

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

SR3: RENEWAL OF THE NUCLEAR POWER 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 generation;
- an operating life of between 50 and 60 years for the reactors in the current nuclear power plant fleet;
- phased replacement of the reactors in the current nuclear power plant fleet with EPR™ reactors only, which could eventually make up 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).

ESTIMATED QUANTITIES OF RADIOACTIVE WASTE AND RADIOACTIVE MATERIALS THAT MAY BE RECLASSIFIED AS WASTE AT END OF FACILITY LIFE

Radioactive waste at end of facility life, in m³		
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 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 civil spent 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 at the end of 2016.

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

1 Some or all of the depleted uranium may be recyclable 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 generation;
- an operating life of 40 years for the 58 PWR reactors and 60 years for the Flamanville EPR^{TM};
- the early shutdown of spent ENU fuel reprocessing to avoid holding separated plutonium. Spent MOX and ERU fuel is not reprocessed.

ESTIMATED QUANTITIES OF RADIOACTIVE WASTE AND RADIOACTIVE MATERIALS THAT MAY BE RECLASSIFIED AS WASTE AT END OF FACILITY LIFE

Radioactive waste at 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 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 civil spent fuel	54
Non-irradiated separated plutonium, in all its physicochemical forms[1]		2
Other materials		70

At 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 life, 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 aboard.

SUMMARY OF SCENARIOS

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

Materials are allocated to a waste category based on their type. This does not determine the management solution that will be selected, particularly in the case of uranium. As part of the 2016-2018 PNGMDR, studies are underway regarding management options available in the event that depleted uranium and RepU is reclassified as waste in the future.

		SR1	SR2[1]	SR3	SNR
Continuation or shutdown of nuclear power generation		Continuation (total operating life of between 50 and 60 years)	Continuation (total operating life of 50 years)	Continuation (total operating life of between 50 and 60 years)	Shutdown after 40 years (except for EPR™, in which case after 60 years)
Type of reactor deployed in future fleet		EPR then FNR	EPR then FNR	EPR	/
Reprocessing of spent fuel		All: ENU, ERO, MOX and FNR	All: ENU, ERO, 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	ERU, MOX, FNR and depleted uranium
HLW	Uranium oxide fuel from nuclear power reactors (ENU, ERU)	-	-	3,700 tHM	25,000 tHM
	Uranium and plutonium mixed oxide fuel from nuclear power reactors (MOX, FNR)	-	-	5,400 tHM	3,300 tHM
	Vitrified waste	12,000 m³	10,000 m³	9,400 m³	4,200 m³
ILW-LL		72,000 m³	72,000 m³	70,000 m³	61,000 m³
LLW-LL	Waste[2,3]	190,000 m³	190,000 m³	190,000 m³	190,000 m³
	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 m³	1,900,000 m³	2,000,000 m³	1,800,000 m³
VLLW[4]		2,300,000 m³	2,200,000 m³	2,300,000 m³	2,100,000 m³

Notes

Waste quantities are stated in "conditioned equivalent volume".
Material quantities are stated in "tonnes of heavy metal".
Fuel quantities can also be stated in "number of fuel 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 low-level long-lived uranium conversion treatment residue produced with effect from 2019.
3 Value re-evaluated since the 2015 edition of the National Inventory.
4 Includes VLLW waste generated by heat treatment of nitrate-containing effluent at Malvési.

INSIGHTS GAINED FROM 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 with scenario SR2.

HLW

- The quantity of vitrified waste produced is linked to the operating lives of the reactors in the current nuclear power plant fleet.
- The decision whether or not to renew the current nuclear power plant fleet, and where applicable, the type of reactor that would replace current reactors, are two factors that would impact 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

- The quantity of waste produced is linked to the operating lives of the reactors in the current nuclear power plant fleet.
- The ILW-LL waste forecasts in scenarios SR1, SR3 and SNR have been reassessed in the light of operating experience feedback and new industrial targets.
- The decision whether or not to renew the existing nuclear power plant fleet, and if applicable, the types of reactor that would replace the current units are factors that impacting the quantity and type of waste at the end of the fleet's life.

LLW-LL

- Most LLW-LL is produced when dismantling existing facilities. The volume of this waste at end of facility life is therefore unrelated to the scenarios associated with the forecast inventories.
- Depleted uranium in all its physicochemical forms: in scenarios SR1 and SR2, all 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, implying that uranium enrichment operations also continue, increases the depleted uranium inventory. The shutdown of nuclear power production assumed in scenario SNR would lead to the shutdown of enrichment and MOX fuel fabrication operations and, in turn, mean that stocks are not recovered. Considering its characteristics, depleted uranium could be treated likeLLW-LL waste.
- Uranium from spent fuel reprocessing in all its physicochemical forms: 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 would result in the definitive shutdown of RepU recycling and, in turn, mean that stocks of RepU are not recovered. Considering its characteristics, reprocessed uranium could be treated like LLW-LL waste.

LILW-SL **VLLW**

- The quantity of waste produced is directly linked to the operating lives of the reactors in the current nuclear power plant fleet.

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

ANDRA
Agence nationale pour la gestion des déchets radioactifs

inventaire.andra.fr, the reference website for all radioactive materials and waste on French territory.

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