ESSENTIALS

National Inventory of Radioactive Materials and Waste

2020

ANDRA
French national radioactive waste management agency

Liberté • Égalité • Fraternité
République Française
Ministère de la Transition Écologique et Solidaire

Every year, Andra publishes the **Essentials, a condensed version of the National Inventory of Radioactive Materials and Waste**.

This document presents the changes to the inventory of radioactive materials and waste produced in France. This work is supplemented every three years by "forecast inventories" that provide estimates of the quantities of materials and waste based on several contrasting scenarios relating to the future of facilities and France's long-term energy policy.

It constitutes a valuable tool for guiding French policy on the management of radioactive materials and waste.

You can view all of the data from the *National Inventory* on the dedicated website at: **inventaire.andra.fr**, and as open data at: **data.gouv.fr**.

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The figures given 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 2018. The radiological inventories and forecasts are taken from the 2018 edition of the National Inventory.

1
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. Since this radioactivity can present a risk to health, 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 at international level (European Council Directive 2011/70/Euratom of 19 July 2011).

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

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, etc.

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

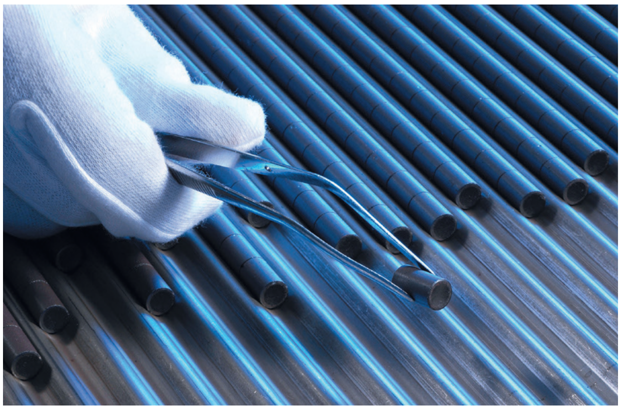
Yellowcake

- **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 to produce electricity.

It comprises:

- 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 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 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 (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, etc.).

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 effluent, which is composed of traces of rare-earth residues that will be reused.

METHODS OF 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 option – the PNGMDR requires the owners of radioactive materials and waste to regularly check whether the materials stored are recoverable.

Spent fuel storage pool at the Orano reprocessing plant in 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 of retrieving 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 Environmental 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)	VSLW Management through radioactive decay	VLLW Surface disposal (Industrial facility for grouping, storage and disposal)	
Low-level waste (LLW)		LILW-SL Surface disposal (Aube and Manche disposal facilities)	LLW-LL Near-surface disposal under development
Intermediate-level waste (ILW)			ILW-LL Deep geological disposal under development (Cigeo project)
High-level waste (HLW)	Not applicable		HLW

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. This 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 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

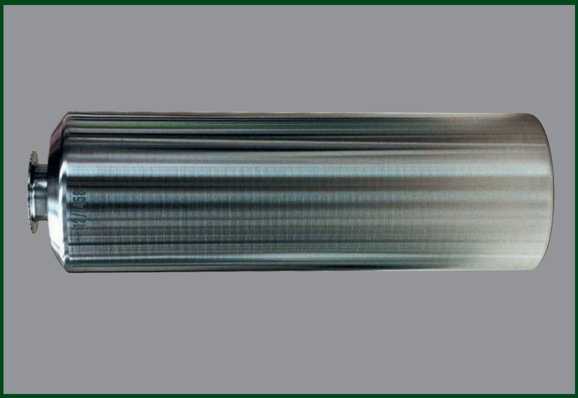
HLW HIGH-LEVEL WASTE

High: several billion Bq/g

Long 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 residues from the chemical dissolution of spent fuel. This waste is encapsulated in glass, then conditioned in stainless steel containers.



HLW packages

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]

This is primarily waste from the metal structures that surround the fuel (hulls and end caps), which come from the reprocessing of spent fuel[2] and, to a lesser extent, 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.

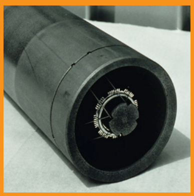
Hulls from the zirconium alloy cladding that covers fuel pellets

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, uranium-conversion residues from the Orano Malvési plant (see page 18), and operating waste from the La Hague reprocessing plant.

1 Cigeo 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 reprocessing sites pending disposal.

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

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

Short (up to around 300 years)

Existing surface disposal[1]

This principally comes from operations (the processing of liquid effluent or filtration of gaseous effluent, 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 productsin a laboratory

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

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 sector and research. 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

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 adequately confine the waste and isolate it from humans and the environment over a period commensurate with the hazards it poses, 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 *département* 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;
- the near-surface disposal facility, under development, for the disposal of low-level long-lived waste (LLW-LL);
- the 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 on processing and conditioning methods. The final decision is based on the characteristics of the package produced.

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)

In addition, for very short-lived waste (VSLW), the radioactivity drops significantly in a few months, or even a few days or hours. 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, primarily due to their special physical or chemical characteristics. By convention, this is referred to as waste without a specific disposal solution (DSF). Once the waste has been processed, conditioned or characterised, where necessary, it will be sent to the appropriate management solution.

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

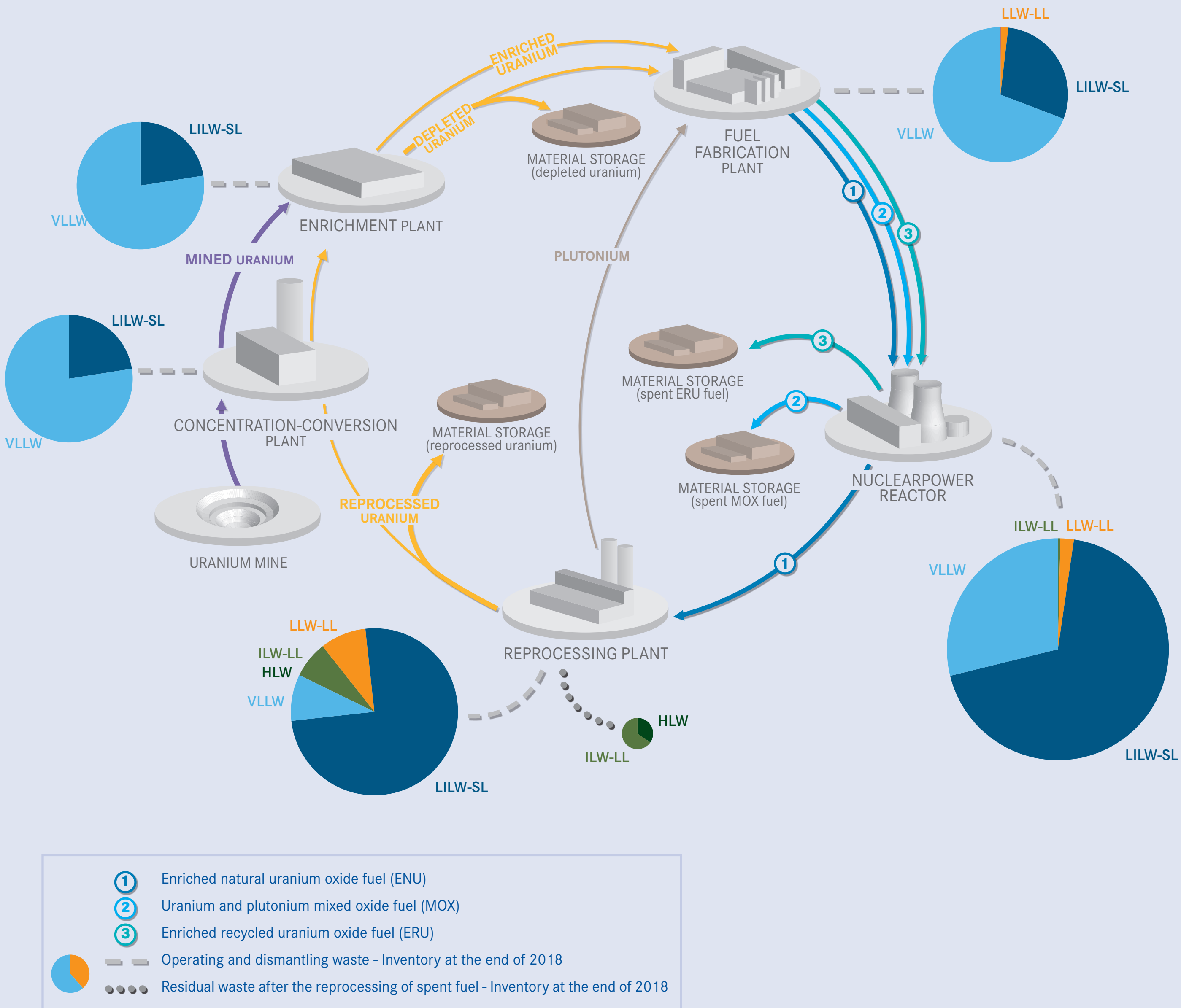
Most radioactive materials and waste produced by the nuclear power sector come from running the facilities that manufacture, use and then reprocess nuclear fuel.

This includes the operation of the facility and its dismantling.

The majority of waste produced during the operation of these facilities is sent 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: Cigeo. The nuclear power sector generates a small amount of low-level long-lived waste (LLW-LL), for which a disposal facility is 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.



2
INVENTORY OF RADIOACTIVE MATERIALS AT END OF 2018

MATERIALS RECORDED

Andra performs an annual inventory of all the radioactive materials present on French territory as on 31 December every year, based on the information provided by the holders of these 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) by virtue of Article R. 1333-154 of the French Public Health Code.

For fissile materials, the main holders of materials are those involved in the nuclear fuel cycle, all the operators of nuclear reactors (power, defence or research facilities) and those 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) a unit 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).

Uranium hexafluoride crystals

INVENTORY OF RADIOACTIVE MATERIALS

The table below shows the inventory of radioactive materials at the end of 2018 and the difference with the previous year.

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

Category of material		End of 2018	2017-2018 difference
Natural uranium	Mined natural uranium, in all its physicochemical forms	35,900	+ 5,400
	Enriched natural uranium, in all its physicochemical forms	3,340	- 200
	Depleted uranium, in all its physicochemical forms	318,000	+ 4,000
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]	31,500	+ 1,000
Uranium oxide fuel from nuclear power reactors (ENU, ERU)	Fuel before use	276	- 61
	Fuel in use in nuclear power plants	4,360	+ 150
	Spent fuel awaiting reprocessing	12,000	- 100
	Non-irradiated fuel scrap awaiting reprocessing	-	-
Uranium and plutonium mixed oxide fuel from nuclear power reactors (MOX, FNR)	Fuel before use or in production	-	- 22
	Fuel in use in nuclear power plants	424	- 7
	Spent fuel awaiting reprocessing	2,140	+ 110
	Non-irradiated fuel scrap awaiting reprocessing[2]	282	+ 6
Research reactor fuel	Fuel before use	0.02	+ 0.02
	Fuel in use	0.8	0
	Other spent civil fuel	60	+ 1
Non-irradiated separated plutonium, in all its physicochemical forms		56	+ 2
Thorium, in the form of nitrates and hydroxides		8,570	0
Materials in suspension (by-products of rare earth ore processing)		5	0
Other materials[3]		70	0
Spent fuel for defence purposes		194 tonnes	0 tonnes

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

In the current framework of nuclear power generation, radioactive materials are used as fuel, processed 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 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 2018

Andra performs an annual inventory of all the radioactive waste present on French territory as on 31 December of every year, based on the information provided by the waste holders. 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: 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 will receive high-level waste (HLW) and intermediate-level long-lived waste (ILW-LL)), additional conditioning, known as 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 correspond to the radioactive waste already disposed of at Andra facilities, or due to be managed by Andra.

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

Category	End of 2018	2017-2018 difference
HLW	**3,880**	+ 140
ILW-LL	**43,000**	+ 200
LLW-LL	**93,700**	+ 100
LILW-SL	**945,000**	+ 6,000
VLLW	**557,000**	+ 20,000
DSF	**1,350**	- 420
Total	**~ 1,640,000**	~ +30,000

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

The differences observed between the quantity of waste at the end of 2017 and that at the end of 2018 can be explained by:

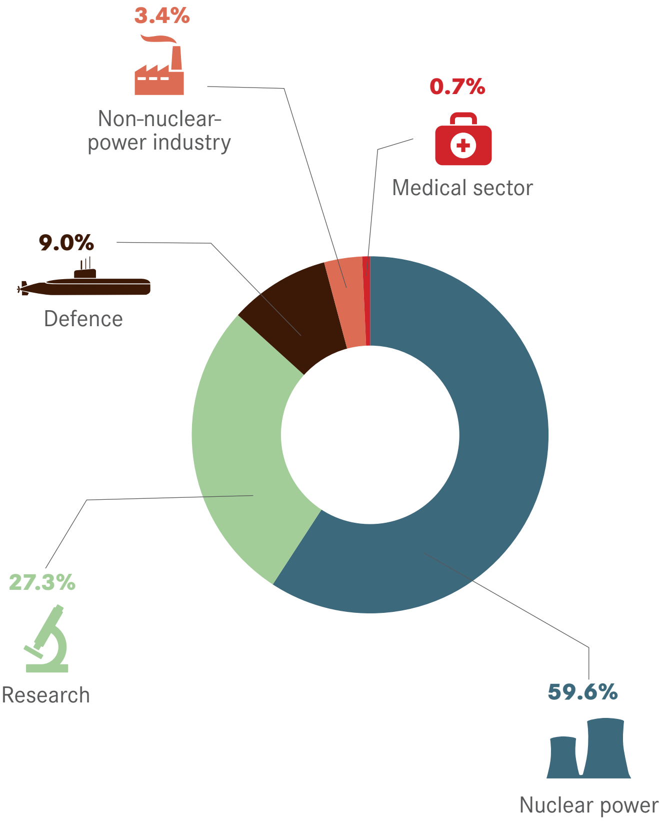
- ongoing waste production for all categories;
- waste containing mercury or metallic mercury now generally being reported in the VLLW category, following the recommendation of the working group on waste without a specific disposal solution (DSF) to remove mercury-containing waste from the DSF category;

INVENTORY OF VOLUMES (m³) OF WASTE AT PRODUCER/HOLDER SITES AND DISPOSED OF IN ANDRA FACILITIES AT THE END OF 2018

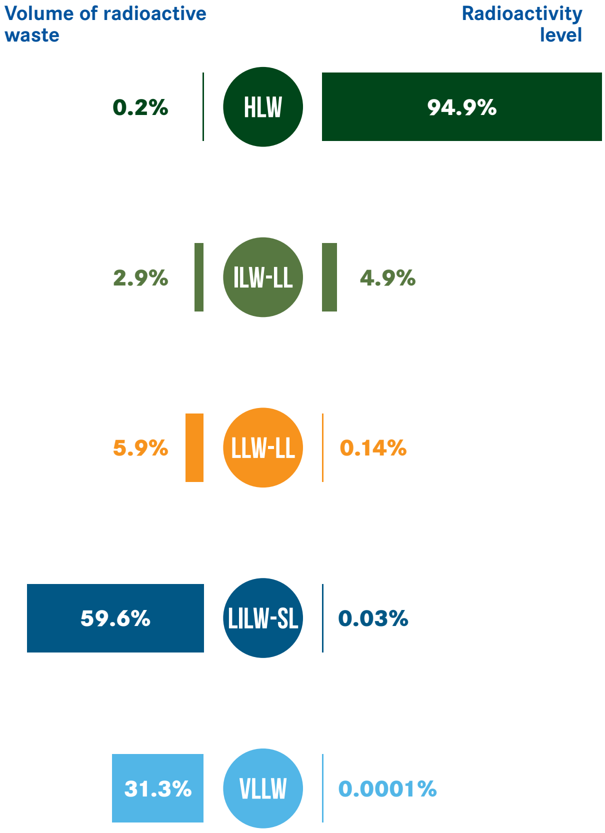
Category of radioactive waste	Total	At producer/holder sites	Disposed of in Andra facilities	Existing disposal capacity
HLW	**3,880**	3,880	0[1]	0[1]
ILW-LL	**43,000**	43,000	0[1]	0[1]
LLW-LL	**93,700**	93,700	0[1]	0[1]
LILW-SL	**945,000**	82,000	862,000	1,530,000
VLLW	**557,000**	181,000	376,000	650,000
DSF	**1,350**	1,350	-	-

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 2018



The breakdown of waste volumes and radioactivity levels 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 repository for HLW and ILW-LL is currently under development (Cigeo). The repository for LLW-LL 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

	End of 2018	2017-2018 difference
VSLW	**1,980**	- 20

The quantity of very short-lived waste is almost stable in comparison to 2017. These volumes are not included in the inventory.

SPECIFIC CASE OF WASTE FROM ORANO MALVÉSI

Uranium conversion treatment residues (RTCU) from the Orano Malvési plant is partly made up of legacy waste. Work is under way 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 2019 will no longer be managed alongside legacy RTCU, and should be directed towards VLLW and LLW-LL management solutions after processing and conditioning.

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

	End of 2018	2017-2018 difference	End of 2030 (data from 2018 edition)	End of 2040 (data from 2018 edition)
Settling ponds	**65,200**	+ 400	0	0
Legacy RTCU	**282,000**	0	310,000	310,000
LLW-LL RTCU	**0**	0	24,000	40,000
Nitrated effluent	**427,000**	+ 133,000	200,000	110,000

These volumes are not included in the inventory and forecasts.

The waste from Malvési includes nitrated effluent stored in liquid form. As for the effluent stored in open-air ponds, its volume varies according to weather conditions. The difference in quantities between 2017 and 2018 can be explained by greater rainfall in 2018, causing an increase in the volume of nitrated effluent.

WASTE PROCESSED USING SPECIFIC MANAGEMENT METHODS

(this waste is not included in the inventory)

- **Waste disposed of on or near the sites of nuclear facilities or plants.** Its radioactivity is in the order of several becquerels per gramme (several thousands of tonnes).
- **Residues from uranium ore processing** present on former mining sites. These are long-lived residues 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, approximately several becquerels per gramme (around 3,000 tonnes).
- **Waste containing naturally occurring radioactive material (NORM) managed through on-site disposal.** This is generated by the processing of raw materials that contain naturally occurring radionuclides but that are not used for their radioactive properties. It is largely comparable to VLLW (around 50 million tonnes).

Residues resulting from the treatment of very slightly radioactive materials were used as backfill at 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 is permanently 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
REMINDER OF THE 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 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 forecast 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 shut down. 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 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 cover all radioactive substances that have been and will be produced by the facilities licensed at the end of 2016 (existing fleet).

Nuclear power plant cooling towers

The materials and waste generated by the operation of new reactors to replace the reactors in the current nuclear power plant fleet are not included[1].

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

The term "at the end of facility life" means 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.

DETAILS REGARDING SCENARIO ASSUMPTIONS

TYPES OF NUCLEAR POWER REACTOR

In these scenarios, a distinction is made 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. The dismantling of these reactors generates low-level long-lived (LLW-LL) graphite waste;
- **Pressurised water reactor (PWR):** second-generation reactor. There are 58 reactors of this type currently in operation in France, with an electrical output of 900, 1,300 or 1,450 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 currently authorised for use in 24 PWR reactors. Enriched reprocessed uranium (ERU) fuel made from uranium oxide is authorised for use in four reactors;
- **EPR™ (European Pressurised Reactor):** third-generation pressurised water reactor with an electrical output of around 1,650 MW. 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 can use uranium and plutonium mixed oxide fuel and multi-recycling is possible.

REACTOR OPERATING LIFE

The scenarios use different operating lives in their assumptions for current nuclear power reactors. These assumptions do not prejudge 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 act on energy transition for green growth, the holders of radioactive materials and waste used as their assumption a total nuclear power production capacity below 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 provides 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 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 reuse at a later date. Irradiated MOX fuel unloaded from the PWRs still contains a significant quantity of plutonium. Multi-recycling involves reprocessing irradiated fuel to extract the recoverable materials, and then manufacturing 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 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 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:
- nuclear power production will be continued;
- reactors in the current nuclear power plant fleet will have an operating life of between 50 and 60 years;
- reactors in the current nuclear power plant fleet will be gradually replaced with EPR™ reactors, then with FNR reactors, which could eventually make up the entire future fleet;
- all spent fuel will be reprocessed. By extension, this assumes that:
  - there will be fuel reprocessing plants available to perform these operations,
  - the materials separated during fuel reprocessing will be recycled in current PWR reactors and EPR™ reactors (mono-recycling), then in FNR reactors that enable 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 to replace 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. 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*. Just 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:
- nuclear power production will be continued;
- all reactors will have an operating life of 50 years;
- reactors in the current nuclear power plant fleet will be gradually replaced with EPR™ reactors, then with FNR reactors, which could eventually make up the entire future fleet;
- all spent fuel will be reprocessed. By extension, this assumes that:
  - there will be fuel reprocessing plants available to perform these operations,
  - the materials separated during fuel reprocessing will be recycled in current PWR reactors and EPR™ reactors (mono-recycling), then in FNR reactors that enable 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 to replace 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. 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 nuclear power production continuing with the deployment of EPR™ reactors only.
The key assumptions made for this scenario are:

- nuclear power production will be continued;
- reactors in the current nuclear power plant fleet will have an operating life of between 50 and 60 years;
- reactors in the current nuclear power plant fleet will be gradually replaced with EPR™ reactors alone, which could eventually make up the entire future fleet;
- only spent ENU fuel will be reprocessed, with spent MOX and ERU fuel not being reprocessed. By extension, this assumes that:
  - there will be fuel reprocessing plants available to perform these operations,
  - materials separated during ENU fuel reprocessing will be 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 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 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 to replace the reactors in the current fleet, as they had not been licensed at 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 must then be sent for disposal. Spent MOX and ERU fuel is not reprocessed. It is considered as waste and assumed that it will 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 shutdown of the nuclear programme.
The key assumptions made for this scenario are:

- nuclear power production will be shut down;
- the 58 PWR reactors will have an operating life of 40 years and the Flamanville EPR™ will have an operating life of 60 years;
- spent ENU fuel reprocessing will be discontinued early 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 m³		
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 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 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 presuppose the management solution that will be selected, particularly in the case of uranium. 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 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, 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	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 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 residues that will be produced from 2019.
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 effluent at Malvési.

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 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. ▪ Whether the current nuclear power plant fleet is renewed and the type of reactor that would replace 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	▪ The quantity of waste produced is linked to the operating lives of the reactors in the current nuclear power plant fleet. ▪ The incorporation of operating experience feedback and new industrial targets has led the ILW-LL waste forecasts in scenarios SR1, SR3 and SNR to be re-evaluated. ▪ Whether the current nuclear power plant fleet is renewed and the type of reactor that would replace 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	▪ The quantity of waste at the end of facility life is not dependent on the scenarios. ▪ 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, which means 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. Due to the characteristics of depleted uranium, it could be categorised with 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 would result in the definitive shutdown of RepU recycling and, in turn, mean that stocks of RepU are not recovered. Due to the characteristics of reprocessed uranium, it could be categorised with 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. Extending the operating life would increase the quantity of operating waste generated.

ANDRA
French national radioactive waste management agency

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

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