NATIONAL INVENTORY OF RADIOACTIVE MATERIALS AND WASTE

ESSENTIALS
2015

ANDRA
French national radioactive waste management agency

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CONTENTS

1. ISSUES AND PRINCIPLES OF RADIOACTIVE MATERIALS AND WASTE MANAGEMENT

WHAT IS RADIOACTIVE WASTE? WHAT IS A RADIOACTIVE MATERIAL?

- **The use of radioactive properties** in various industries results in the production of waste.
- **A radioactive substance contains natural or artificial radionuclides** and its activity or concentration justifies radiological protection monitoring.
- **Radioactive waste** refers to radioactive substances for which **no subsequent use** is planned or intended.
- **Many types of radioactive waste resemble conventional waste**: tools, clothing, plastics, scrap metal, rubble, etc.
- **A radioactive material** is a radioactive substance for which **subsequent use is planned or intended** (after processing, if necessary).
- **Radioactive materials mainly consist of ores, sands and metals** in their natural state or after physical-chemical transformations to make them usable.
- Radioactive materials and wastes contain radionuclides that emit radiation and present a health risk. They cannot be managed like conventional waste and undergo specific processing.

Radioactive waste is produced during **operation** of facilities using radioactive substances, and also during **dismantling** of these facilities.

ORIGIN OF RADIOACTIVE WASTE

Radioactivity is used in many industries and sectors.
The five main industries/sectors are:

1 NUCLEAR POWER INDUSTRY

Mainly nuclear power plants for electricity production, as well as facilities to manufacture and process nuclear fuel (mining and processing of uranium ore, chemical conversion and enrichment of uranium concentrates, fuel fabrication, spent fuel reprocessing, and recycling of part of the materials removed from spent fuel).

2 DEFENCE INDUSTRY

Mainly deterrence activities, including nuclear powered ships or submarines, the associated research activities, and various uses by the French Army.

3 RESEARCH

Research for civil nuclear applications along with medical, agronomy, chemistry, biology, and nuclear physics and particle laboratories.

4 OTHER INDUSTRIES
(in addition to nuclear power)

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

5 HEALTHCARE

Therapeutic, diagnostic and research activities (scintigraphy, radiotherapy, etc.).

NOTE

Most of the waste produced by facility operation is short-lived waste. It is sent to the Aube industrial disposal facilities run by Andra (French National Radioactive Waste Management Agency). Intermediate level long-lived waste (ILW-LL) is stored at its production site.

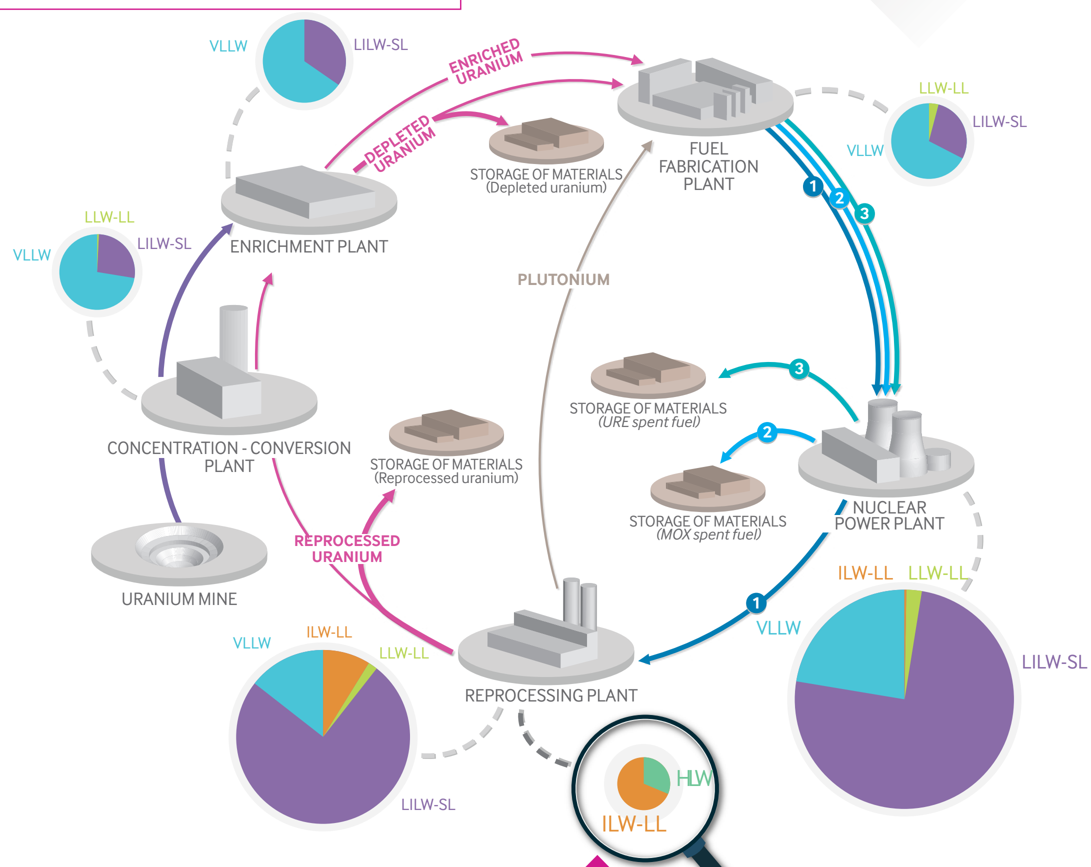
Dismantling of all facilities also produces waste, most of which is very low level waste (VLLW).

Radioactive materials are currently reused, or stored until reuse is possible. Research is being conducted on a cycle with 4th generation fast breeder reactors, aimed at improving the recycling of materials, specifically MOX and URE fuels as well as depleted uranium.

CURRENT MANAGEMENT OF RADIOACTIVE MATERIALS AND WASTE PRODUCED BY THE NUCLEAR POWER INDUSTRY

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

Operation of a facility includes its service life and dismantling.



LEGENDS

1 Enriched natural uranium oxide fuel (UOX)

2 Plutonium and uranium mixed oxide fuel (MOX)

3 Re-enriched reprocessed uranium oxide fuel (URE)

Operation and dismantling waste

Waste from spent fuel reprocessing

SPENT FUEL REPROCESSING

Reprocessing separates out usable materials (plutonium, uranium) from residues that are included in HLW and ILW-LL. This waste is stored at the production sites, which ensure spent fuel reprocessing.

DEFINITION: STORAGE

Storage consists in temporarily placing radioactive materials or waste in a specially designed facility, with the intention of removing them later.

DIFFERENT TYPES OF RADIOACTIVE MATERIALS AND WASTE

The main radioactive materials, in terms of activity level and volume, are:

- Uranium at different stages of transformation: mined uranium (natural), uranium enriched or depleted in fissile isotopes, uranium from spent nuclear fuel reprocessing;
- New nuclear fuel, currently in use in nuclear reactors, or spent fuel awaiting subsequent reprocessing;
- Plutonium from spent nuclear fuel reprocessing;
- Ores containing natural radionuclides, but which are not used for their radioactive properties, and any by-products (by-products from mining rare earths, for example).

Radioactive waste generally contains a mixture of radionuclides (radioactive isotopes: uranium, caesium, iodine, cobalt, radium, tritium, etc.). Depending on its composition, the waste has higher or lower levels of radioactivity lasting for varying periods of time. **It is classified into five categories:**

CATEGORIES OF WASTE

HLW

High-level waste

Mainly from spent fuel reprocessing.
Its radioactivity is on the order of several billions of becquerels per gram.

ILW-LL

Intermediate-level long-lived waste

Also mainly from spent fuel reprocessing.
Its radioactivity is between one million and one billion becquerels per gram.

LLW-LL

Low-level long-lived waste

Mainly graphite waste from first-generation graphite-moderated gas-cooled reactors, also radium-bearing waste.
The radioactivity of graphite waste varies between 10,000 and 100,000 becquerels per gram. The radioactivity of radium-bearing waste varies between a few tens and a few thousands of becquerels per gram.

LILW-S

Low and intermediate-level short-lived waste

Mainly from the operation and dismantling of nuclear power plants, fuel cycle facilities, research centres and, in small part, medical research. The radioactivity of this waste varies between a few hundreds of becquerels per gram and one million becquerels per gram.

VLLW

Very-low-level waste

Mainly from the operation, maintenance and dismantling of nuclear power plants, fuel cycle facilities and research centres.
Its radioactivity is generally less than 100 becquerels per gram.

HOW ARE RADIOACTIVE MATERIALS CURRENTLY MANAGED?

Radioactive materials are **stored** in facilities suited to their characteristics, until they can be used or re-used. For certain materials, such as plutonium from uranium oxide spent fuel reprocessing, this re-use has been in place in industry for more than twenty years: these materials are **recycled.** For other materials, re-use is only envisaged: based on the PNGMDR (French national radioactive materials and waste management programme), owners are to periodically check whether stored materials are **reusable**.

NOTE

Spent fuel recycling consists of separating ultimate waste from materials and of using, in new fuels, fissile materials (plutonium, uranium, etc.) from a previous cycle (mono-recycling in case of one irradiation, multi-recycling in case of several successive passes).

Some waste, mainly from the medical or research sectors, contains radionuclides with very short half-lives. This waste loses its radioactivity in a few months or days, or even hours. It is thus stored on site until radioactive decay has occurred, then is disposed of using a hazardous, non-hazardous or inert waste solution, depending on its physical, chemical and biological characteristics.

HOW IS RADIOACTIVE WASTE CURRENTLY MANAGED?

DEFINITION: DISPOSAL

Disposal entails placing radioactive waste in a specially designed facility for potentially permanent storage.

In order to isolate waste until its radioactivity decreases to levels not associated with risks for humans and the environment, in France waste is managed in dedicated disposal facilities after storage.

Three types of disposal facilities are planned for radioactive waste, **each with characteristics suited** to the level of radioactivity and the half-life:

- **Surface disposal facilities;** two centres in the Aube department and operated by Andra are used for very low level waste (VLLW) and low and intermediate level short-lived waste (LILW-SL)[1];
- **Near-surface disposal facility**
- **Deep geological repository**

these two types of disposal are under study by Andra, in compliance with the French Law of 28 June 2006, for HLW, ILW-LL and LLW-LL.

According to the French Environmental Code, after storage, ultimate radioactive waste that, for reasons of nuclear safety and radiological protection, cannot be transferred to a surface or near-surface facility must be **disposed of in a deep geological repository**.

Some of the waste is old. It was classified when it was produced and stored. Before being disposed of, this waste undergoes a new detailed study and if necessary, processing. This may lead to changing the disposal route.

[1] *Also, the Manche disposal facility operated from 1969 to 1994 and which is currently in a monitoring phase.*

2. INVENTORY OF RADIOACTIVE WASTE AT THE END OF 2013

Andra inventories the radioactive waste present in France on 31 December of every year, based on the information provided by the waste holders. There are **over 1000 waste holders, all sectors and industries combined.**

NOTE

Packaging consists of placing waste in a container suited to its radioactivity level and its half-life, and then immobilising it, if necessary, in a blocking material.

The inventoried waste volumes correspond to the volumes of packaged waste, i.e. for which no further processing is planned by the producers before disposal. This conditioned waste corresponds to primary packages.

For assessment purposes, a uniform counting unit has been adopted: the "equivalent packaged volume". For waste whose packaging has not yet been determined, assumptions are made to assess the equivalent packaged volume.

In the specific case of deep geological disposal, additional packaging may be necessary for handling, safety or reversibility purposes. Only the volume of primary packages is indicated in this document.

NOTE

At this phase in the design of deep geological repositories, the HLW disposal package volume could be 2 to 3 times greater than that for primary packages; ILW-LL package volume could be 5 to 6 times greater.

WASTE TO BE MANAGED BY ANDRA

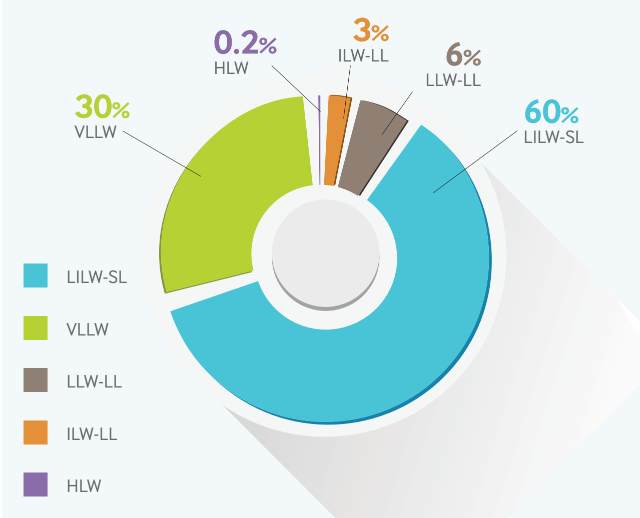
The tables and graphs below present the 31/12/2013 results based on declarations made by waste holders in 2014, for waste already transferred to Andra disposal facilities or slated to be managed by Andra.

RESULTS AND CHANGES OVER TIME FOR VOLUME (m³) OF WASTE

CATEGORY	WASTE AT THE END OF 2013	2013/2010 DIFFERENCE*
HLW	3,200	500
ILW-LL	44,000	4,000
LLW-LL	91,000	4,500
LILW-SL	880,000	52,000
VLLW	440,000	77,000
TOTAL	~1,460,000	~140,000

The differences were calculated based on the exact numbers then rounded.

BREAKDOWN OF RADIOACTIVE WASTE VOLUMES BY CATEGORY, END OF 2013



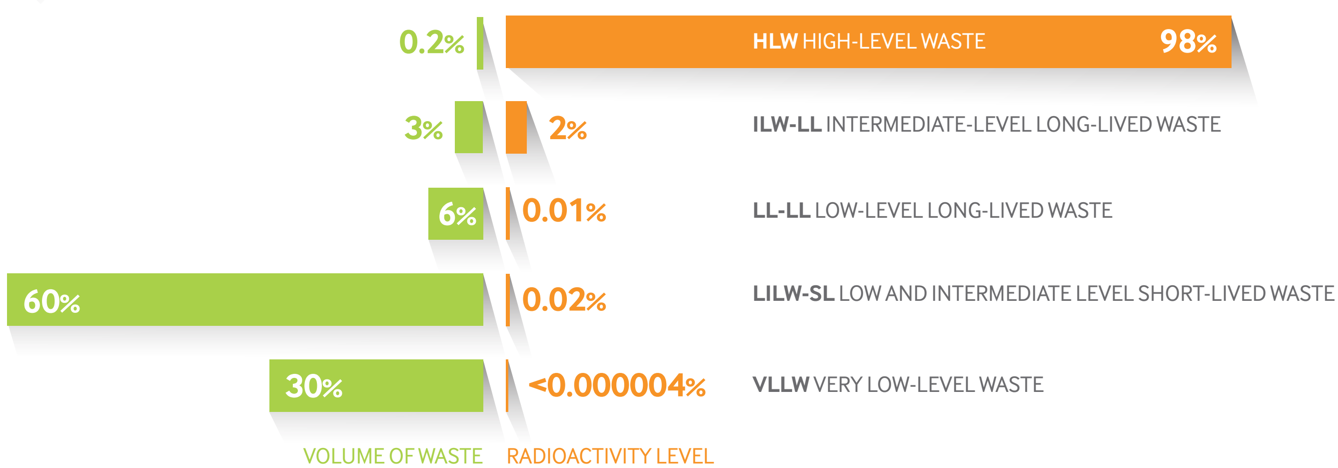
The differences observed between the waste quantities at the end of 2010 and the quantities at the end of 2013 are due to current waste production.

These differences are also due to:

- The decision to reprocess spent fuel from reactor EL4 (Brennilis), previously considered as waste;
- Changes in packaging assumptions for bituminised sludge drums at Marcoule, resulting in an increase in the packaged volume of ILW-LL (+3,300 m³). These changes, however, do not correspond to an increase in the quantity of radioactive waste;
- Changes in packaging assumptions for radium-bearing waste from monazite processing, resulting in an increase in the packaged volume of LLW-LL (+3,000 m³). These changes, however, do not correspond to an increase in the quantity of radioactive waste;
- Consideration of KDU (sludge from washing UF6 containers) from Pierrelatte, which contributes to an increase in the volume of LLW-LL;
- Optimisation of processing and packaging;
- Characterisation efforts so that waste is oriented toward the correct category.

The convention for calculating radiological activity was changed (consideration of progeny radioelements in secular equilibrium) relative to the 2012 edition of the national inventory.

BREAKDOWN OF VOLUME AND RADIOACTIVITY LEVEL OF RADIOACTIVE WASTE PRESENT AT THE END OF 2013



WASTE MANAGED ACCORDING TO HISTORICAL MANAGEMENT METHODS

(This type of waste is not included in the results)

- ***The tailings left over from uranium ore processing*** *have been definitively disposed of at the mines sites. They represent about 50 million tonnes, spread between 20 sites. They are long-lived residues with an activity level comparable to that of VLLW.*
- ***Other types of waste have been disposed of in facilities that fall outside Andra's scope of responsibility:*** *in-situ disposal facilities (e.g. mounds or backfill) or conventional disposal facilities. The activity of this waste is basically the same as that of VLLW.*
- ***France also conducted two radioactive waste dumping campaigns*** *in the Atlantic in 1967 and 1969, representing 14,200 tonnes of waste. A total of 3,200 tonnes of waste from the French nuclear testing programme in the Pacific were also dumped between 1967 and 1982.*

3. INVENTORY OF RADIOACTIVE MATERIALS AT THE END OF 2013

Andra inventories the radioactive materials present on French territory on 31 December of every year. The holders of these materials are fewer in number than the holders of waste. For fissile materials, the holders are mostly either part of the nuclear fuel cycle, nuclear reactor users (defence, research, etc.) or in the chemical industry, in which case they use radioactive materials for other properties than radioactivity (e.g. rare earth mining).

DEFINITION: tHM

tHM (tonne of heavy metal): tonne of uranium, plutonium or thorium.

MATERIALS QUANTITIES

CATEGORY		MATERIALS AT THE END OF 2013
Natural uranium	mined	26,000 tHM
	enriched	2,800 tHM
	depleted	290,000 tHM
Uranium from spent fuel reprocessing	reprocessed	27,000 tHM
	enriched	-
Uranium oxide fuel from nuclear power reactors (UOX, URE)	scrap	-
	new	440 tHM
	in use	4,600 tHM
	awaiting reprocessing	12,000 tHM
Plutonium and uranium mixed oxide fuel from nuclear power reactors (MOX, Superphenix, Phenix)	scrap	230 tHM
	new	38 tHM
	in use	410 tHM
	awaiting reprocessing	1,700 tHM
Research reactor fuels	new	0.2 tHM
	in use	0.2 tHM
	awaiting reprocessing	75 tHM
Plutonium		52 tHM
Thorium		8,500 tHM
Materials in suspension		5 tHM
Other materials		72 tHM
National defence fuels		156 t

The categories of materials to be declared were re-defined in the French Order of 4 April 2014, amending the Order of 9 October 2008; this makes it difficult to compare the quantities at the end of 2010 and those at the end of 2013.

This redefinition of categories affects, among other things, the declaration methods for uranium and plutonium.

In previous editions, new fuels and scrap were counted as uranium and plutonium. The amending Order of 4 April 2014 defines new categories for different types of new fuel and different types of scrap. The quantity of plutonium in this edition is thus much lower than that in the 2012 edition because it no longer includes the plutonium from new fuel or scrap[2].

In addition:

- the spent fuel from reactor EL4 (Brennilis) is now considered as materials (~50 tHM). This uranium oxide spent fuel is counted in the category "Fuel from research reactors awaiting reprocessing" in the previous table;
- a uniform unit was used (except for Defence): tonne of heavy metal (tHM), resulting in significant reductions in the quantities for thorium and especially for materials in suspension (MIS);
- the second Superphenix core, which was not and will not be irridiated and was classified in the category "Other materials", since it does not correspond to either fuel before use or spent fuel.

RADIOACTIVE MATERIALS, EXCLUDING DEPLETED URANIUM, ARE BROKEN DOWN AS FOLLOWS:

INDUSTRY OR SECTOR	QUANTITY
Nuclear power	75,000 tHM
Research	150 tHM
Non-nuclear power industries	8,600 tHM
Medical	0 tHM
Defence	156 t

[2] *Newly manufactured fuels are considered as "new fuels" once they are accepted by the customer. Before that, they are considered as quantities of plutonium and uranium.*

4 . FORECAST QUANTITIES OF RADIOACTIVE MATERIALS AND WASTE BASED ON INDUSTRY SCENARIOS

Regulations require **holders** of radioactive materials and waste to make production forecasts for the end of 2020 and 2030. Since 2014, waste holders must also provide forecasts that take the end of facility operation into consideration and indicate the service life and dismantling assumptions used to establish these forecasts.

For the nuclear power industry, the key assumptions are:

- **An average service life of 50 years for all reactors**; this assumption reflects the strategic orientations of EDF relative to the longer operation of the fleet and has no effect on the decisions made by the ASN (French Nuclear Safety Authority) in the area of safety or any changes that may occur in French energy policy;
- **Start of reactor dismantling and production of graphite LLW-LL anticipated around 2025.** It should be noted that the dismantling of the fleet's first-generation facilities is underway with the production of short-lived waste (LILW-SL and VLLW), some of which has already been sent to surface disposal facilities;
- **Reprocessing of all spent fuel,** which corresponds to the current management policy; by common agreement, the assumption is that current fuel reprocessing plants will operate long enough to ensure these operations. It is further assumed that materials separated will be reused in the current nuclear power fleet or in a future fleet;
- **A spent fuel reprocessing flow of around 1000 tonnes per year.**

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

REGULATIONS

French Order of 9 October 2008 (amended by Order of 4 April 2014) on the type of information that managers in charge of nuclear activities and the companies identified under Article L.1333-10 of the French Public Health Code are obliged to collate, update and periodically send to Andra.

FORECAST OF RADIOACTIVE WASTE VOLUMES (m³) AT THE END OF 2020 AND 2030 AND FINAL FORECASTS ACCORDING TO INDUSTRY SCENARIOS:

CATEGORY	QUANTITIES AT THE END OF 2013	FORECASTS FOR THE END OF 2020	FORECASTS FOR THE END OF 2030	FINAL FORECASTS
HLW	3,200	4,100	5,500	10,000
ILW-LL	44,000	48,000	53,000	72,000
LLW-LL	91,000	92,000	120,000	180,000
LILW-SL	880,000	1,000,000	1,200,000	1,900,000
VLLW	440,000	650,000	1,100,000	2,200,000
TOTAL	~1,460,000	~1,800,000	~2,500,000	~4,300,000

COMPARISON OF FORECASTS FOR THE END OF 2020 AND 2030 ASSESSED AT THE END OF 2010 AND 2013:

CATEGORY	FORECAST FOR THE END OF 2020 ASSESSED IN 2013	FORECAST FOR THE END OF 2020 ASSESSED IN 2010
HLW	4,100	4,000
ILW-LL	48,000	45,000
LLW-LL	92,000	89,000
LILW-SL	1,000,000	1,000,000
VLLW	650,000	760,000
TOTAL	~1,800,000	~1,900,000

CATEGORY	FORECAST FOR THE END OF 2030 ASSESSED IN 2013	FORECAST FOR THE END OF 2030 ASSESSED IN 2010
HLW	5,500	5,300
ILW-LL	53,000	49,000
LLW-LL	120,000	133,000
LILW-SL	1,200,000	1,200,000
VLLW	1,100,000	1,300,000
TOTAL	~2,500,000	~2,700,000

The reasons for the changes in provisional HLW and ILW-LL quantities at the end of 2020 and 2030 are the same as for the changes in quantities at the end of 2013, namely:

- changes in packaging assumptions for bituminised sludge drums at Marcoule, resulting in an increase in the packaged volume of ILW-LL. These changes, however, do not correspond to an increase in the quantity of radioactive waste;
- the decision to reprocess spent fuel from reactor EL4 (Brennilis), previously considered as waste.

The LILW-SL production forecasts have not changed significantly since the last edition.

The update to the nuclear facility dismantling schedule, related to the availability of the future LLW-LL disposal centre, led to a reduced VLLW and LLW-LL production forecast for the end of 2030.

The final forecasts assessed on 31/12/2013 were declared for the first time in 2014.

FORECASTS OF RADIOACTIVE MATERIALS QUANTITIES (tHM) AT THE END OF 2020 AND AT THE END OF 2030:

CATEGORY		QUANTITIES AT THE END OF 2013	FORECASTS FOR THE END OF 2020	FORECASTS FOR THE END OF 2030
Natural uranium	mined	26,000 tHM	25,000 tHM	25,000 tHM
	enriched	2,800 tHM	960 tHM	960 tHM
	depleted	290,000 tHM	330,000 tHM	410,000 tHM
Uranium from spent fuel reprocessing	reprocessed	27,000 tHM	34,000 tHM	44,000 tHM
	enriched	-	-	-
Uranium oxide fuel from nuclear power reactors (UOX, URE)	scrap	-	-	-
	new	440 tHM	440 tHM	440 tHM
	in use	4,600 tHM	4,600 tHM	3,900 tHM
	awaiting reprocessing	12,000 tHM	12,000 tHM	13,000 tHM
Plutonium and uranium mixed oxide fuel from nuclear power reactors (MOX, Superphenix, Phenix)	scrap	230 tHM	240 tHM	200 tHM
	new	38 tHM	45 tHM	45 tHM
	in use	410 tHM	490 tHM	390 tHM
	awaiting reprocessing	1,700 tHM	2,600 tHM	4,000 tHM
Research reactor fuels	new	0.2 tHM	0.2 tHM	0.3 tHM
	in use	0.2 tHM	0.1 tHM	0.1 tHM
	awaiting reprocessing	75 tHM	75 tHM	77 tHM
Plutonium		52 tHM	33 tHM	39 tHM
Thorium		8,500 tHM	8,500 tHM	8,400 tHM
Materials in suspension		5 tHM	3 tHM	-
Other materials		72 tHM	72 tHM	72 tHM
National defence fuels		156 t	212 t	271 t

The forecasts in the table above do not take into consideration any requalification of materials as waste by the minister in charge of energy.

5. PROSPECTIVE INVENTORIES

Projections of the waste and materials that will be produced by all facilities up to end-of-life will be presented here. These quantities are based on two nuclear power policy scenarios that are purposely quite different. Those scenarios do not pre-empt possible evolutions of the future French energy policy. The activity of industries other than the nuclear power industry is assumed to be identical in the two scenarios.

In both cases, the inventory only covers waste produced by authorised facilities as of the end of 2013, even though in the "continuation scenario", new facilities are commissioned.

SCENARIO 1

NUCLEAR POWER PRODUCTION CONTINUES

This scenario is based on two elements: continued production of electricity by nuclear means and continued use of the current strategy for spent fuel reprocessing. The average service life assumed is 50 years for all reactors, with a guaranteed total maximum capacity for nuclear power production of 63.2 GWe. It is also assumed that all fuel consumed by authorised reactors at the end of 2013 is reprocessed to separate materials (uranium, plutonium) from ultimate waste. No spent fuel is directly disposed of and all the plutonium extracted from spent fuels is recycled, in the current or future fleet, in the form of uranium and plutonium mixed oxide fuel.

Given the number and age of reactors currently authorised to use this type of fuel, the nuclear power fleet as it exists today will make it possible to use separated plutonium until approximately 2029. Beyond that, the rate at which spent fuel is reprocessed and thus the production of plutonium will depend directly on the rate at which new reactors consuming this fuel are commissioned. The spent fuels (UOX, MOX) produced by the existing fleet until end-of-life would represent about 30,000 tHM to be recycled.

SCENARIO 2

NUCLEAR POWER PRODUCTION IS DISCONTINUED

This scenario assumes that the existing fleet is discontinued, in which case spent fuel reprocessing would stop before shutdown of the reactors to avoid storing separated plutonium. It also assumes a 40-year reactor service life. Plutonium recycling is limited to the MOX fuel fabrication necessary for the operation of reactors currently authorised to use this type of fuel. Based on the shutdown dates for these reactors, the separation of plutonium by spent fuel reprocessing would cease to be necessary starting in 2019.

In this scenario, around 28,000 tHM of spent fuel, UOX and MOX, would become waste and have to be disposed of (in the same conditions as for HLW).

ESTIMATION OF FINAL WASTE PRODUCED IN THE TWO FUTURE SCENARIOS CONSIDERED:

		SCENARIO 1	SCENARIO 2
HLW	**Uranium oxide fuel from nuclear power reactors**		~50,000 assemblies
HLW	**Plutonium and uranium mixed oxide fuel from nuclear power reactors**		~7000 assemblies
HLW	**Vitrified waste (m^3)**	10,000	3,900
ILW-LL (m^3)		72,000	65,000
LLW-LL (m^3)		180,000	180,000
LILW-LL (m^3)		1,900,000	1,800,000
VLLW (m^3)		2,200,000	2,100,000

The difference in HLW and ILW-LL waste volumes between the continuation and discontinuation scenarios is due to the differences in industrial strategy for spent fuel reprocessing and the different service lifetimes considered. The increase in LILW-SL and VLLW is due only to the difference in service lifetimes considered in each of the scenarios.

NOTE

Spent fuel is currently not considered waste, and is therefore not packaged for disposal. Since the average volume of a fuel assembly is 0.19 m^3, these assemblies represent a volume of 12,000 m^3 before packaging. In 2012, Andra checked the feasibility of disposing of spent fuels. The disposal container designs used for this demonstration represent a volume of around 89,000 m^3 (around 8 times the non-packaged volume).

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