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Nuclear Illustrative Programme Presented under Article 40 of the Euratom Treaty - Final (after opinion of EESC)

{COM(2017) 237 final}

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1 Introduction

This Staff Working Document has been prepared to support the analysis of the Nuclear Illustrative Programme of the Commission (PINC), and is a collection of factual data gathered from several sources. Member States and nuclear operators have provided some data through questionnaires prepared by the European Commission on specific matters where public information was limited. Information on future investments in nuclear facilities has been taken from notifications received by the Commission in the framework of Article 41 of the Euratom Treaty or in public statements issued by investors or Member States. Public sources and voluntary contributions that are listed in the bibliography have been used as well.

This document focuses on nuclear power generation. Non-power applications of the nuclear energy and R&D activities are considered in the framework of other Communications.[1] The scope of the analysis includes Member States with operational or shut-down nuclear power reactors, namely: Belgium, Bulgaria, Czech Republic, Germany, Spain, Finland, France, Croatia, Hungary, Italy, Lithuania, the Netherlands, Romania, Sweden, Slovenia, Slovakia and the United Kingdom. Poland has also been included since it has expressed its intention to potentially develop commercial nuclear power reactors in the future.

The document is structured following the investment needs of the different steps of the nuclear fuel cycle, which may be broadly defined as the set of processes and operations needed to manufacture nuclear fuel, its irradiation in nuclear power reactors and storage, reprocessing or disposal of the irradiated fuel. The nuclear fuel cycle starts with uranium exploration and ends with disposal of the materials used and generated during the cycle. For practical reasons the cycle has been further subdivided into two stages: the front-end and the back-end.

Unless otherwise stated, all figures are expressed in real terms in year-2015 EUR.

1.1 Overview of the European nuclear industry

Nuclear energy accounts for 28% of the domestic production of energy in the EU, and 50% of its low carbon electricity,[2] with 129 nuclear power reactors in operation in 14 EU Member States managed by 18 nuclear utilities.[3] The contributions of nuclear energy to the gross electricity production and to the energy mix differ among Member States.

Europe has gained a leading role in nuclear technology, built on more than 60 years of experience in nuclear power while developing and implementing the highest nuclear, radiation and waste safety standards for the protection of workers, patients and the general public. Europe also holds a significant export potential in a global market with investment estimates of EUR 3 trillion until 2050,[4] and the industry, according to internal sources, currently supports 800 000 jobs[5].

There are currently four reactors under construction, located in France, Slovakia and Finland. Projects for the construction of nuclear power plants are facing a challenging regulatory and market environment.[6] Additional

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[1] For example: "Towards an Integrated Strategic Energy Technology Plan" (C(2015) 6317 final); and "Energy Technologies and Innovation" (COM(2013) 253 final). The specific objectives of the Euratom Research and Training Programme can be found in http://ec.europa.eu/programmes/horizon2020/en/h2020-section/euratom.

[2] Source: Eurostat, May 2015.

[3] Source: Euratom Supply Agency, Annual Report (2014).

[4] Source: Nuclear Energy Agency, The economics of the back-end of the nuclear fuel cycle (2013). FX rate used: 1 USD = 0,75 EUR.

[5] Source: FORATOM, Position paper regarding the PINC (2015). Avaliable at http://www.foratom.org/public/position-papers/8650-nuclear-indicative-programme-pinc/file.html. An estimation of 900 000 jobs was considered during the symposium on the "Benefits and limitations of nuclear fission for a low-carbon economy" held in Brussels on 26-27 February 2013 (http://ec.europa.eu/research/energy/euratom/publications/pdf/study2012_synthesis_report.pdf).

[6] For further description of the investment perspectives in electricity markets, see Staff Working Document (2015)142 accompanying the Communication (2015) 340 "Launching the public consultation process on a new energy market design".

pressure is being put on the costs side, since new build projects in Europe are experiencing significant delays and cost overruns. Under these conditions, returns on investments in nuclear generation are difficult to assess.

Concerning the fleet in operation, the average age of the European reactors is approaching 30 years and questions about long term operation[7] (LTO) and/or replacement of the existing capacity are gradually becoming more important for Member States and national safety authorities. Europe is furthermore moving to a phase where the back end of the fuel cycle will receive much greater attention.

Figure 1 Share of nuclear in national (gross) electricity mix, 2013[8]

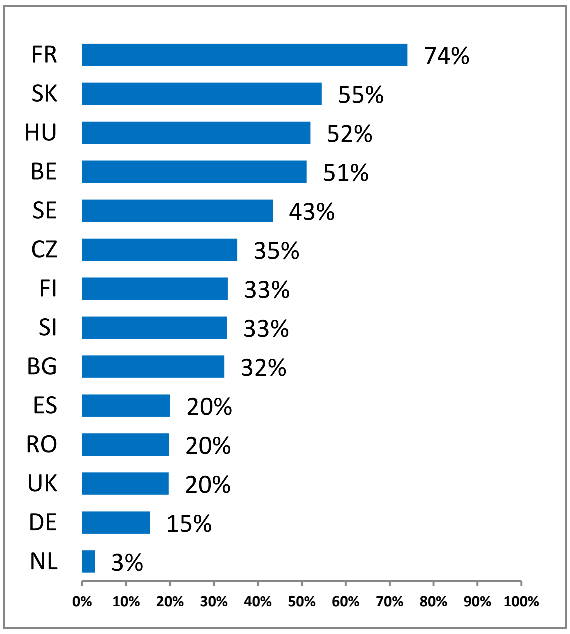
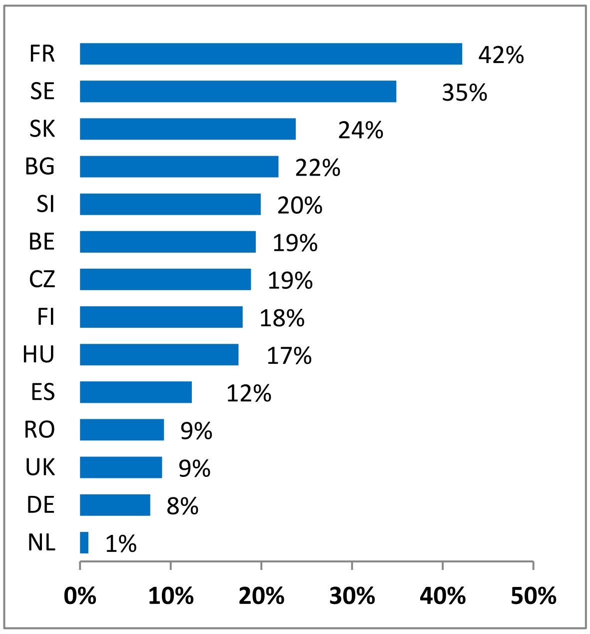


Figure 2 Share of nuclear in national energy mix, 2013[9]



The role of nuclear energy in the European electricity system

Nuclear energy is a source of low-carbon electricity. The International Energy Agency (IEA) estimated for example that limiting temperature rise below 2 °C would require a sustained reduction in global energy CO_2 emissions (measured as energy-related CO_2/GDP), averaging 5,5 % per year between 2030 and 2050. A reduction of this magnitude is ambitious, but has already been achieved in the past in Member States such as France and Sweden thanks to the development of nuclear build programmes.[10]

Nuclear energy also contributes to improving the dimension of energy security (i.e. to ensure that energy, including electricity, is available to all when needed), since:[11]

a) fuel and operating costs are relatively low and stable;
b) it can generate electricity continuously for extended periods; and
c) it can make a positive contribution to the stable functioning of electricity systems (e.g. maintaining grid frequency).

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[7] Operating a nuclear power plant beyond an established time frame set forth by, for example, licence term, design, standards and/or regulations.

[8] Source: Eurostat; Gross electricity generation in nuclear power plants and gross electricity generation. Data extracted in April 2015.

[9] Source: Eurostat; Gross inland energy consumption by fuel type. Data extracted in April 2015.

[10] The nuclear power programmes resulted in a reduction in France's energy-related CO_2/GDP ratio averaging 5,4 % per year between 1978 and 1988, and in Sweden averaging 6,2 % between 1979 and 1989. Source: International Energy Agency, Energy and climate change (2015). Note: at the Paris climate conference (COP21) in December 2015, the governments agreed a long-term goal of keeping the increase in global average temperature to well below 2°C above pre-industrial levels and to aim to limit the increase to 1,5°C.

[11] Source: International Energy Agency, World Energy Outlook (2014).

Finally, nuclear can play an important role in reducing the dependence on fossil fuel energy imports in Europe.[12]

2 The front-end of the nuclear fuel cycle

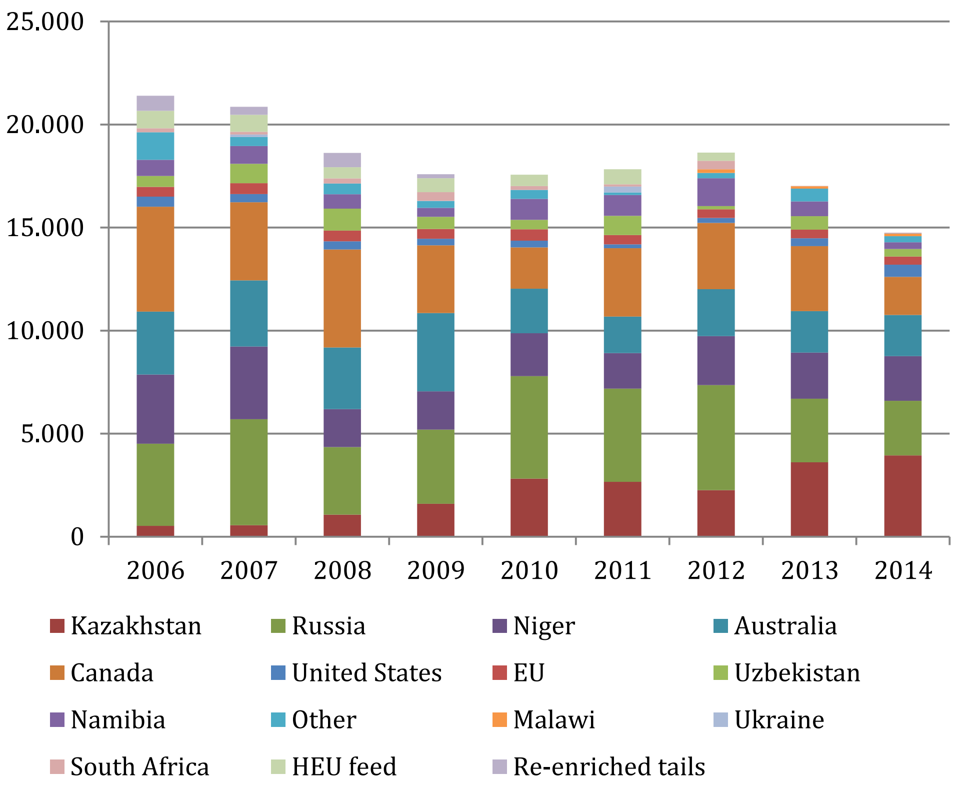
Front-end processes involve uranium ore exploration and mining, processing, conversion and enrichment and finally, fabrication of fuel assemblies which are specific to each reactor type.

The EU industry is active in all parts of the nuclear fuel supply chain. While uranium production in the EU is limited, EU companies have mining operations in several major producer countries. The EU nuclear industry also has significant capacities in conversion, enrichment, fuel fabrication and spent fuel reprocessing, making it a global technology leader.

2.1 Demand for natural uranium

EU demand for natural uranium represents approximately one third of the global uranium requirements. It is obtained from a diversified group of suppliers, most important of which was in 2014 Kazakhstan, origin of 3 941 tons of uranium (tU) or 27 % of total deliveries, followed by Russia with an 18 % share or 2 649 tU (including purchases of natural uranium contained in EUP)[13] and Niger in the third place with 2 171 tU or 15 %. Australia and Canada accounted for 14 % and 13 % respectively.

Figure 3 Purchases of natural uranium by EU utilities by origin, 2006–14 (tU) (%)[14]



Deliveries of natural uranium to EU utilities occur mostly under long-term contracts, the spot market representing less than 5 % of total deliveries.

[12] Source: see note 11. The analysis shows that in the low nuclear scenario, energy self-sufficiency rates in countries that utilise nuclear power are reduced compared with the reference scenario, leaving them more susceptible to supply disruptions and sudden increases in fossil fuel prices.

[13] EUP: Enriched Uranium Product, i.e. UF6 enriched, typically to between 3% and 5% U235 content.

[14] Source: Euratom Supply Agency, Annual Report (2014).

In terms of indigenous production, the uranium mined in the Czech Republic and Romania covers approximately 2 % of the EU utilities' total requirements.

Regarding security of supply, since the 1990's EU dependency on imported uranium has remained constant. Taking all fuel loaded into EU reactors in 2014, including natural uranium feed, reprocessed uranium and MOX fuel (mixture of uranium and plutonium oxides), the requirements amounted to 17 094 tU. The quantity of natural uranium originated in EU accounts for approx. 400 tU per year, which together with savings in natural uranium resulting from MOX fuel and reprocessed uranium usage gives the quantity of feed material coming from indigenous and secondary sources, equivalent to 12,5 % of the EU's annual natural uranium requirements.

Figure 4 Natural uranium included in fuel loaded by source - 2014[15]

Source	Quantities (tU)	Share (%)
Uranium originated outside EU	14 955	87,5
Uranium originated in EU (approximate annual production)	400	2,3
Reprocessed uranium	582	3,4
Savings from MOX	1 156	6,8
Total annual requirements	17 094	100

Uranium inventories owned by EU utilities at the end of 2014 totalled 52 898 tU, an increase of 3 % from the end of 2013 and 15 % from the end of 2009. The inventories represent uranium at different stages of the nuclear fuel cycle (natural or reprocessed uranium and uranium in-process for conversion, enrichment or fuel fabrication), stored at EU or foreign nuclear facilities.

2.2 Conversion

All the European conversion services are located in France, in the Comurhex plants (Malvesi for the conversion of uranium concentrate into uranium tetrafluoride, or UF4, and Pierrelatte for the following conversion into uranium hexafluoride, or UF6). Their combined nominal capacity is 15 000 tU/y. of which about 70 % was utilised during 2015.[16] Other plants are located in the United States, Canada, Russia and China (which operates a conversion facility for internal demand). It is worth noting that two thirds of the western conversion capacity is located in North America, whereas two thirds of the western enrichment capacity is in the EU. This situation puts some pressure onto the transportation system, especially given the limited number of ships and harbours that are permitted to handle nuclear materials. However, to date transit problems have not been noted.

Regarding security of supply, the current EU capacity operated by AREVA would be sufficient to cover most of EU needs, if run at full capacity and if no exports were taking place. AREVA has invested an estimated EUR 1 billion[17] in the past years to modernize its conversion facilities.

2.3 Enrichment

Most of the commercial nuclear power reactors operating or under construction require uranium enriched in the U235 isotope for their fuel, which is higher than the level that can be found in mined uranium, making enrichment a critical step of the fuel cycle. There are four major enrichment producers on the global market (AREVA, URENCO, Rosatom and CNNC).

Several governmental authorities have adopted measures affecting international trade in enriched uranium.[18] For example, governmental policies favouring domestic enrichment make access of foreign suppliers to the

[15] Source: see note 14.

[16] Source: World Nuclear Association webpage, accessed on 25/10/2015.

[17] Source: AREVA, Contribution of AREVA to the preparation of the Nuclear Illustrative Programme (2015).

[18] Source: URENCO, Information on the uranium enrichment industry and market (2015).

markets for enrichment services in Russia and China difficult. Anti-dumping restrictions are in place in the United States on imports of low-enriched uranium from France.[19]

In 2014, 68% of the EU requirements of enrichment services were met by the two European enrichers (AREVA and URENCO) while 26% were delivered by Russian suppliers within the Rosatom group.

AREVA and URENCO jointly own the Enrichment Technology Company Limited (ETC) with enrichment assets in the United Kingdom, Germany, the Netherlands and the United States that account for 32% of the global capacity.[20] AREVA has recently invested an estimated EUR 4 billion in building the Usine Georges Besse II in Tricastin. The project was designed in several modules, spreading construction and commissioning of the new capacity over several years; at the end of 2014, 88% of the final capacity was operational. The new facility supplies enriched uranium to all kinds of European reactors.[21]

Regarding security of supply, the EU-based capacities operated by AREVA and URENCO would be more than sufficient to cover all EU needs if no exports were taking place. However, since EU companies are major suppliers for worldwide customers, a significant part of their production is exported. Maintaining idle reserve capacity is not practical, since the used centrifuges must be kept continuously in operation, which also requires energy. Therefore, centrifuge enrichment plants are operating at full capacity, although part of the capacity may be used for below optimum activities, such as re-enrichment of depleted uranium, depending on market conditions. This provides some margin of flexibility for increasing output.[22] In addition, capacity expansions can be achieved through the modular construction of centrifuge enrichment facilities, should the demand increase.

Figure 5 Providers of enrichment services delivered to EU utilities in 2014[23]

Enricher	Quantities (tSW)	Share (%)
AREVA/GBII and URENCO (EU)	8 503	68 %
Rosatom (Russia)	3 197	26 %
USEC (United States)	200	2 %
Others (Note A)	624	5 %
Total	12 524	100 %

Note A: including enriched reprocessed uranium.

2.4 Fuel fabrication

In the EU, there are two distinct nuclear fuel procurement approaches:[24]

- Utilities operating western design reactors usually enter into separate contracts with uranium mining companies, conversion service providers, enrichment service providers and finally fuel assembly manufacturers. This approach allows for diversification of all steps of the front end of the fuel cycle, and for bigger utilities it offers the possibility to maintain several suppliers at all stages.
- Utilities operating Russian design reactors in most cases purchase their fuel as integrated packages of fuel assemblies, including the uranium and related services, from the same supplier (Rosatom). In this approach, there is no diversification, nor backup in case of supply problems. Whereas diversification of the conversion and enrichment services could be implemented immediately, for diversification of

[19] For more information on the anti-dumping procedure, see http://enforcement.trade.gov/frn/summary/france/2015-23050.txt

[20] Source: see note 14.

[21] Source: see note 17.

[22] Source: COM(2014) 330 final, "European Energy Security Strategy".

[23] Source: see note 14.

[24] Source: see note 14.

fuel assembly manufacturing to take place this would require some technological efforts because of the different reactor designs (water-water power reactors, or VVER, 440 and 1000).

While the uranium itself can be purchased from multiple suppliers and easily stored, the final fuel assembly process is managed by a limited number of companies. For the western designed reactors, there are fuel fabrication facilities in Germany, Spain, France, Sweden and the United Kingdom.

The average demand in Europe is 1 600 tU for pressurized water reactors, or PWR, and 300 tU for boiling water reactors, or BWR, per year.[25] Looking at the light water reactor (LWR) fuel fabrication capacities in place in Figure 6, these appear to be sufficient for the current demand.

Figure 6 LWR fuel fabrication capacity in Western Europe, in tons of heavy metal (tHM)[26]

Member State	Company	Site	Conversion	Pelletizing	Rods / Assembly
FR	AREVA NP-FBFC	Romans	1 800	1 400	1 400
ES	ENUSA	Juzbado	0	500	500
DE	AREVA NP-ANF	Lingen	800	650	650
SE	Westinghouse AB	Vasteras	600	600	600
		TOTALS	3 200	3 150	3 150

There are reactors depending on Russian fabrication services in Finland (2 reactors), Bulgaria (2), Czech Republic (6), Hungary (4) and Slovakia (4), in a process that is "bundled" and managed by one Russian company (TVEL/Rosatom) currently with insufficient competition or diversification options.[27] The Russian industry is developing fuel assemblies for western-type pressurised water reactors as well, and could enter this commercial market by 2020.

Regarding security of supply, the European industry would be able to cover all EU needs for western-design reactors, and in principle could also establish the production capacity needed for VVER fuel (i.e. Russian design reactors) as it was already the case in the past.[28] However, developing and licensing fuel assemblies for Russian design reactors would take a few years in normal circumstances (provided that a sufficient market is available to make the investment attractive for the industry), since the licensing of reactor fuel assemblies manufactured by a new supplier requires a full range of safety evaluations for which R&D is to be carried out at EU level, involving industrial and regulatory experts.[29]

While Finland also operates non-Russian design reactors with western fuel supplies, Bulgaria and Hungary are 100% dependent on Russian nuclear fuels (uranium, conversion, enrichment and fuel fabrication). Two other Member States (the Czech Republic and Slovakia) are close to the same level of dependence, although the former has domestic uranium mining and partly diversified enrichment supplies, and the latter has started to diversify enrichment supplies.

In Romania, the two reactors in operation are based on the Canadian CANDU technology and the country is self-sufficient for its fuel needs as it produces uranium and masters the fuel fabrication process, because the uranium used in this type of reactors does not need to be enriched.

Based on average annual EU gross uranium reactor requirements (approximately 17 000 tU/year), current

[25] Source: see note 17.

[26] Source: World Nuclear Association, Fuel market report (2013).

[27] Source: see note 14.

[28] Between 2001 and 2007, Westinghouse delivered a total of seven reload batches to unit 2 at Finland's Loviisa plant. Fuel assemblies were fabricated by ENUSA in Spain. Following some unsuccessful fuel tenders in 2006 and 2007, Westinghouse decided to exit the VVER-440 business. Source: Mark Dye, Jan Höglund, and Ulf Benjaminsson, Diversification of the VVER fuel market. Nuclear Engineering International. (2015).

[29] This licensing process is being analysed in the "European supply of safe nuclear fuel" initiative funded under the Horizon 2020 framework. For more information see http://cordis.europa.eu/project/rcn/196993_en.html

uranium inventories can fuel EU utilities' nuclear power reactors for approximately 3 years.[30] Most EU utilities have inventories for at least one reload. Most vulnerable in terms of security of supply are those utilities that depend on Russian fabricated fuel assemblies (VVER reactors), which cannot be quickly replaced by fuel assemblies from another manufacturer.

The Euratom Treaty has set up a common supply system for nuclear materials, in particular nuclear fuel. It also established the Euratom Supply Agency (ESA) and conferred it the task to guarantee reliability of supplies of the materials in question, as well as equal access of all EU users to sources of supply.

Box 1 - The role of the Euratom Supply Agency[31]

Pursuant to Article 52.2.b of the Euratom Treaty, ESA has the exclusive right to conclude contracts for the supply of nuclear materials (ores, source material and special fissile materials) from inside or outside the Community. The Agency appears as a “single buyer”, whose task is to balance demand and supply and to guarantee the best possible conditions for the EU utilities. In practice, in normal circumstances of supply, the “simplified procedure” (introduced by Art. 5 bis of the Agency’s Rules) is used, by which commercial partners – inside or outside the EU – may negotiate their transactions between themselves with the obligation to subsequently submit their draft contracts to ESA for consideration and conclusion. In any case, even within the framework of the simplified procedure, the Agency maintains the right to object to (and refuse to sign) a contract likely to jeopardise the achievement of the objectives of the Treaty. For that reason, all supply contracts, submitted to ESA for conclusion, undergo a thorough analysis, in the light also of the EU common policy.

The role of ESA is many-fold:

- ESA is actively promoting diversification of sources of nuclear fuel supply, with a view to preventing excessive dependence of EU users from any single, third-country source of supply.
- ESA warns individual users of potential excessive dependence from a single, external source of supply. ESA endeavours to propose alternatives and / or remedial measures to the user concerned.
- In its market-monitoring role, ESA has responsibility for early identification of market trends likely to affect medium- and long-term security of supply of nuclear materials and services in the EU market. In the event such trends were detected, the Agency will communicate, as appropriate, and consider relevant remedial action.
- In the event of a sudden deterioration of the situation in the market requiring a quick reaction (in particular, if external dependence increases significantly in a short period of time or if imports risk to distort competition within the EU internal market), as well as in case a user fails to diversify its sources of supply or to implement remedial measures, ESA shall make use of its powers under Chapter 6 of the Treaty.

Security of Supply conclusions of the 2014 ESA Annual Report[32]

From a security of supply point of view, there should always be at least two alternative suppliers for each stage of the fuel cycle, including fuel assemblies licensed for each reactor. The second best option is to have a diversified portfolio up to the fabrication stage and maintain a strategic stock of fabricated fuel. Ideally, all utilities should hold one or two reloads of fabricated fuel assemblies for each reactor, depending on the size of their reactor fleet and their other electricity generation assets.

For bundled sales of fuel assemblies (i.e. including nuclear material, conversion, enrichment and fuel fabrication), the supplier of fuel assemblies must allow the operator to purchase natural or enriched uranium from other sources as well. In particular for new reactors, the reactor constructor must enable the use of fuel assemblies produced by different fabricators by disclosing fuel compatibility data and allowing the testing of alternative fuel assemblies. Operators should ensure that fuel supply diversification is possible for their reactors at all stages of the fuel cycle.

If an alternative fuel fabricator is not yet available, contacts should be established with potential fabricators interested in developing the required fuel. In such situations, testing of alternative fuel elements can be started with lead-test assemblies. Both operators and national regulators of countries operating VVER reactors could benefit from cooperation in the development, testing and licensing of alternative fuel.

[30] Source: see note 14.

[31] Source: see note 22.

[32] Source: see note 14.

3 Nuclear new build

3.1 Investment costs

The investment costs of a nuclear power plant (NPP) are composed of the overnight costs of construction and the financing costs or interests paid during the construction.

3.1.1 Overnight construction costs

The overnight construction costs are calculated as if the full expenditure was spent ‘overnight’, thus at one instance. They include: a) civil and structural costs, b) mechanical equipment supply and installation, c) electrical and instrumentation and control, d) project indirect costs (i.e. engineering, distributable labour and materials, construction management start up and commissioning), e) owners costs (development costs, insurance, environmental studies, etc…) and a provision for contingency.

The study for the European Commission "Synthesis on the economics of nuclear energy"[33] calculated a generic figure of overnight construction cost based on a sample of 137 data points collected from 28 different sources from 2007 to 2012 with the following results:

Figure 7 Generic Overnight Construction Costs

Type of project (note A)	Number of reactors	Site (note B)	Overnight Construction Cost (note C)
$FOAK_2$	Single unit	Brownfield	4 138 to 5 379 EUR/kWe
$FOAK_2$	Twin unit	Brownfield	3 807 to 4 949 EUR/kWe
NOAK	Single unit	Brownfield	3 476 to 3 997 EUR/kWe
NOAK	Twin unit	Brownfield	3 145 to 3 617 EUR/kWe

Note A "First of a kind" or $FOAK_2$ refers to a technology deployed in a country for the first time but that is already operational somewhere else. $FOAK_1$ would represent a technology which is built for the first time ever, although in the projections presented in this report this case is not considered. "N" of a kind or NOAK refers to the 6^{th} and subsequent reactors built for a particular technology in the same country, reflecting the development of an industrial expertise that reduces the estimated cost.

Note B "Brownfield" refers to an existing nuclear site, as opposed to "greenfield" which is used to represent a new location.

Note C Original figures in EUR_{2012}. Actualisation done using the IHS CERA EPPCI index.

The latest estimates made public on different European new build projects (see Figure 8) are in the high range of the calculations presented in Figure 7 (although it has to be taken into account that Olkiluoto and Flamanville would correspond to $FOAK_1$).

Figure 8 Estimated costs of new build projects under development or consideration

Member State	Total capacity (MWe)	Technology	Number of reactors	Estimated Overnight Construction Cost EUR / kWe
Finland – Olkiluoto[34]	1 670	EPR	1	5 100
Finland – Hanhikivi[35]	1 200	VVER	1	5 000 to 5 800 (note A)
France – Flamanville-3[36]	1 670	EPR	1	6 287

[33] See: D'haeseleer, William D., Synthesis on the Economics of Nuclear Energy. European Commission (2013). Available at: https://www.mech.kuleuven.be/en/tme/research/energy_environment/Pdf/wpen2013-14.pdf

[34] Source: World Nuclear Association webpage, accessed October 2015.

[35] Source: World Nuclear Association webpage, accessed August 2015.

[36] Reuters, September 2015,

Member State	Total capacity (MWe)	Technology	Number of reactors	Estimated Overnight Construction Cost EUR / kWe
Average FOAK single unit	1 500			5 460
Czech Republic – Dukovany & Temelin[37]	2 400	Not chosen	2	4 500
Hungary - PAKS-II[38]	2 400	VVER	2	5 000
Slovakia - Mochovce 3 & 4[39]	940	VVER	2	4 900
UK – Hinkley Point C[40]	3 340	EPR	2	6 755
Average FOAK twin unit	2 270			5 290

Note A: The cost of this project has only been publicly disclosed including financing charges. Since the other estimates are reportedly overnight construction costs only, the lower range of Hanhikivi has been included in the calculation of the total average.

3.1.2 Interest during construction

The interest during construction, or financing cost, is the cost of capital during construction, not only on the debt part, but also to provide an acceptable rate of return to equity investors. The financing costs depend on the number of years of construction and on the interest rate applied. Figure 9 presents a sensitivity analysis of what the interest during construction represents when compared to the overnight construction costs for a series of interest rates (columns) and years of construction (rows).

Figure 9 Illustration of financing costs as a % of overnight construction costs[41]

Construction time/ WACC	4%	5%	7%	10%	13%
5 years	8%	10%	14%	21%	28%
7 years	11%	14%	20%	29%	39%
10 years	19%	25%	37%	57%	80%

The impact of financing costs obviously increases with longer construction times. The innovation in nuclear technology into new generations of larger reactors has generally meant increased construction times, as can be seen in Figure 10. The average time elapsed between the beginning of the construction and the commercial operation in Europe has been 7,8 years.[42] In our cost assumptions we have considered that there is margin for reducing the construction time (e.g. through standardisation of supply chain practices) and have used an estimation of 7 years of construction.

Figure 10 Duration of NPPs construction in Europe[43]

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http://uk.reuters.com/article/2015/09/03/edf-nuclear-flamanville-idUKL5N1190M820150903

[37] Source: World Nuclear Association webpage, accessed October 2015.

[38] Source: Financial Times, April 2015, http://www.ft.com/intl/cms/s/0/985b0cca-e82a-11e4-9960-00144feab7de.html#axzz3qj0j31t7

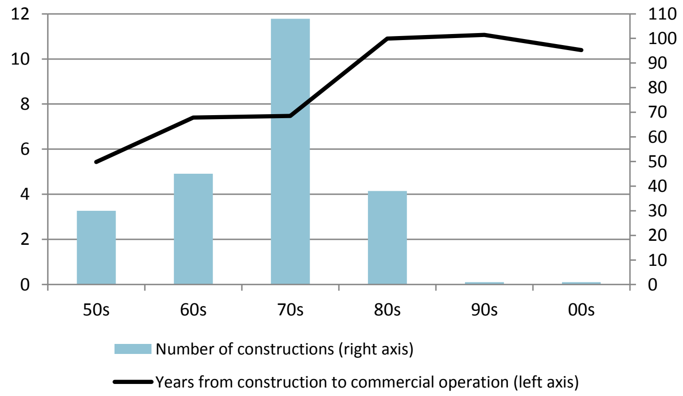
[39] Source: Platts' Nucleonics Week, 30 July 2015.

[40] Source: Financial Times, October 2015. FX rate used: 1 GBP = 1,41 EUR, http://www.ft.com/intl/cms/s/0/912b70e4-683f-11e5-97d0-1456a776a4f5.html#axzz3rNX87Y00

[41] Based on internal calculation.

[42] Calculated from the same set of data used to prepare the graph in Figure 10.

[43] Source: International Atomic Energy Agency, Power Reactor Information System (2015).



Regarding actual real interest rates applicable to building nuclear commercial reactors, these depend on the financing model (own funds, vendor loans, commercial loans, etc…) and risk associated with the project. Based on different investment notifications received by the Commission under the scope of Article 41 of the Euratom Treaty and State Aid investigations, we have assumed an indicative range of between 7 to 10% in our cost estimations.

Box 2 The impact of construction time in the cost of a nuclear power plant

The ongoing constructions of European Pressurized Reactor (EPR) in Finland and France have experienced significant cost overruns (more than 3 times over original budget each). Even though these are first-of-a-kind models with expectedly higher unit costs, they are also consistent with the industry's historical trend of cost escalation. In France, for example, and in spite of some favourable conditions that include centralized decision making, high degree of standardization and regulatory stability, construction costs per MWe in 1974 were 3 times lower than those of the units connected to the grid after 1990.[44]

A recent study[45] has tried to determine the most relevant factors behind this cost escalation, pointing towards the importance of reducing construction lead-times (i.e. latency between the project beginning and completion), which are considered to have a bigger impact on the profitability of nuclear investments than the associated financing costs. The study highlights the following:

a) The nuclear industry has tried to achieve economies of scale by building bigger reactors (e.g. France EPR's 1 650 MWe Vs 1 450 MWe of the N4, 1 300 MWe of the P4 and 900 MWe of the CP series). However, scaling up the capacity of the reactor by 10% would produce increases in the associated lead-time of 3%. Economies of scale, i.e. reductions achieved in the cost per MWe when increasing the size of the reactor, are therefore not an evident conclusion and need to be valued considering all the implications.
b) There is a significant correlation between lead-times and long-term standardization strategies, which occur when a specific design is deployed a significant number of times by the same entity in charge of engineering, procurement and construction. The study also indicates that standardization practices at the level of supply chain have the potential of reducing costs, since constraints due to different component specifications may lead to construction delays.
c) Innovation in nuclear reactors has been closely linked to more demanding safety requirements, which has contributed to a situation where costs increase rather than decrease with accumulated experience.

Finally, the study recommends focusing in standardization practices and vertical integration with the intention of reducing construction times.

3.2 Projection of installed capacity

Based on information collected from public sources as well as reported by Member States under Article 41 of the Euratom Treaty, projections were made regarding the evolution of nuclear power capacity (see Figure 11).[46] These can be summarised as follows:

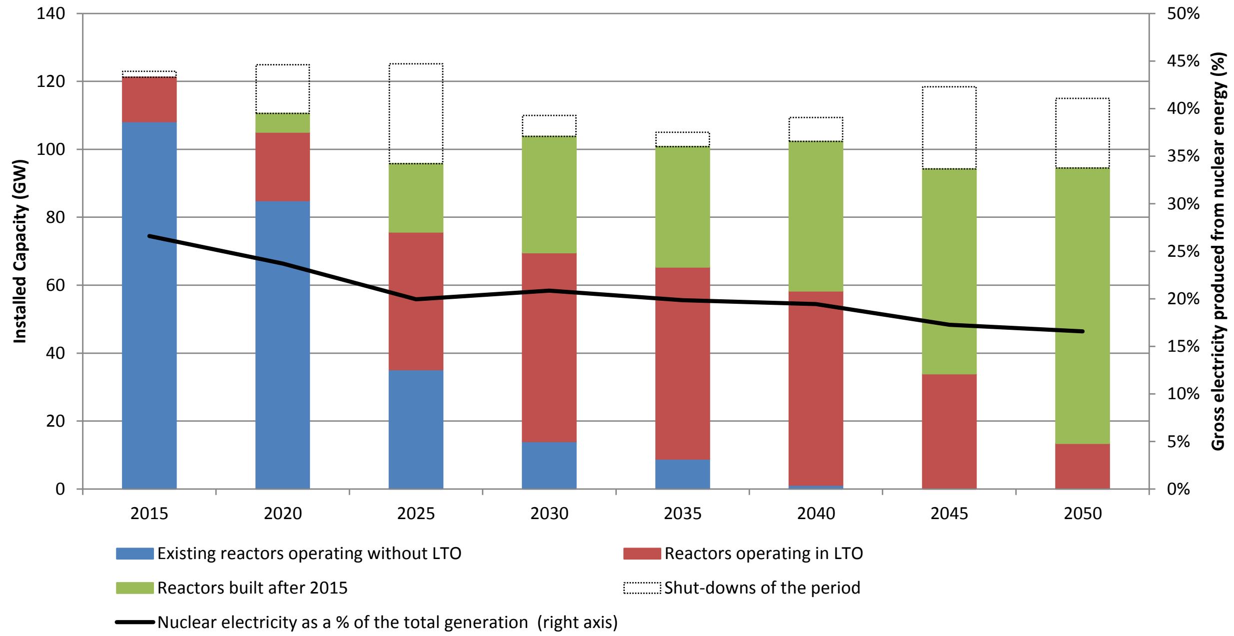
[44] Source: Grubler, A. et al, The French Pressurized Water Reactor Program. Historical Case Studies of Energy Technology Innovation, in Chapter 24, The Global Energy Assessment. Cambridge University Press (2012).

[45] Source: Michel Berthélemy, L. E., Nuclear reactors' construction costs: The role of lead-time, standardization and technological progress. Energy Policy (2015).

[46] This evolution is within the range of the analysis performed by the Commission during the preparation of the 2030 Climate and energy framework, where nuclear capacity was projected to be between 80 GW and 108 GW in 2030, and between 78 and 140 GW in 2050, depending on assumptions and policies considered in the various scenarios. See SWD(2014)255 and SWD(2014)15.

- The importance of long term operations is expected to increase in the coming years,[47] and by 2030 the majority of the fleet would be operating beyond its original design life. Long term operations are expected to represent the majority of nuclear investments in the short to medium term.
- New nuclear capacity would need to be built to partially offset expected shut-downs. New reactors could represent about 80 GW of capacity added by 2050, from which about two thirds could occur in only two Member States (France and United Kingdom). The other Member States where nuclear plants are projected to be built are: Poland, Hungary, Finland, Czech Republic, Slovakia, Bulgaria, Romania and Lithuania.[48]
- The projected capacity in 2050 is between 95 and 105 GW (down from 121 GW in 2015), contributing 17-21% of the total generation of electricity (from 27% today). Out of this nuclear capacity, 14 reactors with a total capacity of 15 GW that were already connected to the grid in 2015 could remain operational still in 2050. However, there is of course a high degree of uncertainty as regards long term projected nuclear capacity. In fact, only a small share of investments in LTO or new built included below have already been approved by national authorities.

Figure 11 Projection of nuclear installed capacity EU28 2015-2050



3.3 Estimated investments in new capacity for the period 2015-2050

Taking the lower range of the projected capacity presented above (95 GW), between EUR 349 and EUR 456 billion would have to be invested in new nuclear generation capacity by 2050 based on the costs estimated in section 3.1.

Figure 12 Projected investments in new nuclear capacity

(EUR billion)	2015-2030	2031-2040	2041-2050	Total
Investments in new capacity	152 – 207	42 – 55	142 - 177	**336 - 439**

[47] Projecting the number of reactors that will be granted with lifetime extensions is subject to significant uncertainties, since regulatory procedures are different reflecting the national legal framework. Depending on the Member State, extensions may have been already granted, operators have expressed their intention for starting the procedure or the regulator has stated expected shut-down dates or scheduled a date for assessing the case.

[48] Projections of new build are similarly subject to several uncertainties. Member States where new nuclear capacity is considered have either stated their intention to have nuclear energy in their energy mix or notified investment projects in new nuclear power. Estimations will be consequently affected if those projects are not completed or if new projects are undertaken.

(EUR billion)	2015-2030	2031-2040	2041-2050	Total
Replacement of shut-downs post 2050 (note A)	-	-	13 - 17	**13 - 17**
Total	**152 – 207**	**42 – 55**	**155 – 194**	**349 - 456**

Note A: The projection considers that after 2050 the contribution of nuclear energy to the total production of electricity will remain stable. To achieve that, the construction of several reactors will have to begin before 2050 in order to be connected to the grid after the cut-off date of 2050.

In case of the higher end of the projection (105 GW), approximately EUR 385 – EUR 500 billion would have to be invested. These investments will depend of the evolution of the market environment[49] and on the ability of the industry to reduce costs, with current constructions such as Flamanville and Olkiluoto experiencing significant delays and cost overruns that undermines the competitiveness of the EU nuclear power industry.

Current investment conditions present a challenging environment for achieving the projections of nuclear new build that are disclosed in this section. There may be a funding shortage of a magnitude that will be mainly determined by the cost of the most competitive technology (taking into account the carbon prices set at the EU emissions trading system, or ETS) and the wholesale market price of electricity. Based on this assessment, the lower end of the projections is used as the reference in this SWD.

A recent study by ICF International[50] calculated the price carbon must fetch for a nuclear new build project in the EU to break-even and thus be financed based on market conditions alone. The conclusions show that, under current investment conditions, none of the carbon price scenarios succeed in making the construction of new nuclear power plants profitable before 2025. Beyond that horizon, the minimum carbon price from which new nuclear capacity would be deployed by means of private financing ranges from 43 to 72 EUR/tCO_2 (see Figure 13). The 2013 EU Reference scenario[51] projects ETS prices of between 35 EUR/tCO_2 in 2030 and 100 EUR/tCO_2 in 2050.

Figure 13 Equilibrium carbon price (EUR/tCO_2)

2020	2025	2030	2035	2040	2045	2050
n.a.	n.a.	61	45	43	48	72

3.4 Licensing process

A licence is a legal document issued by the competent regulatory authority granting authorization to create a nuclear installation and to perform specified activities. The term ‘licensing process’ includes all licensing and authorization processes for a nuclear installation and its activities.[52]

3.4.1 Differences between national regulations

Licensing nuclear facilities is done at the national level. The goals are similar across Member States, since they are based on the objectives that are defined in the Nuclear Safety Directive[53] and on international guidelines such as those issued by the International Atomic Energy Agency (IAEA). However, there are differences which could be classified in two categories:

1. Methodological differences:

[49] For more details see SWD(2015) 340 "Launching the public consultation process on a new energy market design". Further work on this issue will be done in the context of the energy market design, for which legislative proposals will be presented at the end of 2016.

[50] Source: based on the work performed by ICF International in the framework of the Impact Assessment of the Euratom Loan Facility coordinated by DG ECFIN, which is in progress at the date of drafting this SWD. This economic analysis does not consider system factors such as reliability or generation capacity adequacy.

[51] Source: EU Energy, transport and GHG emissions Trends to 2050 - Reference Scenario 2013.

[52] Source: International Atomic Energy Agency, Safety Guide SSS-G-12. (2010).

[53] OJ L 219, 25.7.2014, p. 42.

a) In a prescriptive approach, the regulator establishes relatively detailed requirements for functions and properties of systems, components and structures in a plant.
b) In a non-prescriptive/ goal-setting approach, the regulator establishes specific outcomes for licensees to attain but does not specify how to reach those goals.

2. Differences in the scope of the license:[54]
   In Europe there are generally at least two licensing steps (e.g. construction and operation) and sometimes up to four (e.g. a siting license or a commissioning license). There are exceptions where a one-step licensing process is in place (e.g. the United Kingdom).

   There can also be pre-licensing steps. In the United States, for example, the regulatory authority gives generic approval for a design or a site so that subsequent projects with the same technology do not have to go again through the assessment and evaluation phases. No Member State has developed such a legally binding pre-licensing process in Europe, although the United Kingdom has put in place the Generic Design Assessment (GDA) with the objective of clarifying the licensing process by reviewing potential designs and assess whether they would be licensed once site-specific factors have been taken into account. Similarly, France has developed the "review of safety options" process, by which the vendor presents to the regulator, at the basic design stage of the reactor, the main design characteristics and options defined in terms of safety. Although it is not binding, in practice the regulator would, in a subsequent licensing process, not contradict its own "review of safety options" statement unless there is a compelling reason to do so.

Differences in scope and methodology have led to a situation where the outcome of the license process in a Member State has a limited formal impact in the work of another regulator reviewing the same technology (though regulators generally look at the requirements on which the design was originally based, in particular identifying gaps between regulations). Vendors invest a significant amount of resources in developing their understanding of national regulations and they use this knowledge as a competitive advantage, understandably not sharing lessons learnt with other vendors.

3.4.2 Common aspects

Licensing processes also present some common aspects among Member States. Identifying these will contribute to bring safety improvements. The IAEA's International Nuclear Safety Group (INSAG) has stated that "the general safety goals and requirements for nuclear power plants in different countries, and the design solutions to meet them, have currently reached a state of reasonable harmony. Furthermore, the networks that currently exist have brought mutual understanding and trust among national regulatory authorities. It is therefore the proper time to establish multinational cooperation among nuclear regulators for the safety review of new nuclear power plant designs which are intended for construction in their respective countries."[55]

The benefits of multinational safety reviews listed by the INSAG are the following:

- Multinational cooperation would help to harmonize the global safety approaches and increase safety in general. It would also improve the clarity and transparency of nuclear safety regulations across international borders.
- A thorough safety review could be provided for the benefit of each participating country through the coordinated use of the resources of both regulators and industry.
- Overlapping work resulting from the separate safety assessment processes of different countries could be minimized, and uncertainties in licensing could be reduced.
- Consistent regulatory positions could be developed, thereby promoting international trade in nuclear equipment and bringing cost savings to all parties involved in the nuclear and power production industries.

There is room for harmonization in the licensing practices, especially in the non-site specific steps such as the pre-licensing or the design certification. While experience shows that constant improvements are made to the

[54] Source: World Nuclear Association, Licensing and project development of new nuclear plants. (2015).

[55] Source: International Nuclear Safety Group. Strengthening the Global Nuclear Safety Regime (INSAG-21). (2006).

design following the operating experience and the arrival of new technologies, a reactor's initial design which is determined to be safe in a Member State should not have to be substantially modified to meet licensing requirements in another. Other areas of interest include the licensing of manufacturing practices, since it would bring time savings and enhance competition in the nuclear supply chain.

Progressing towards licensing harmonisation will require the involvement of nuclear power vendors, regulators and technical support organizations. Some of the international initiatives[56] in the field of design harmonization are presented in Box 3.

Box 3 Examples of international initiatives towards license harmonisation[57]

1. Multinational Design Evaluation Programme[58]

The Multinational Design Evaluation Programme (MDEP) is an initiative under the NEA (Nuclear Energy Agency of the Organisation for Economic Co-operation and Development) to develop innovative approaches to leverage the resources and knowledge of national regulatory authorities who are, or will shortly be, undertaking the review of new reactor power plant designs. The MDEP programme incorporates a broad range of activities including the increase of multinational convergence of safety goals, codes and standards.

The MDEP Programme structure includes two groups working in particular towards harmonisation of standards and associated documents:

a) The issue specific Mechanical Codes and Standards Working Group (CSWG) pursues the goals of searching for ways to harmonise and converge national Codes, Standards, and Regulatory requirements and practices in this area while recognizing the sovereign rights and responsibilities of national regulators in carrying out their safety reviews of new reactor designs. Key stakeholders with whom this group interacts routinely include organisations such as the American Society of Mechanical Engineers (ASME), AFCEN, the Canadian Standards Association (CSA), the Japan Society of Mechanical Engineers (JSME), Korea Electric Association (KEA), and NIKIET (Russia). The representatives of the participating organisations have already produced a comprehensive report on the Code comparison for Class 1 Nuclear Power Plant Components.

b) The issue specific Digital Instrumentation and Control Working Group (DICWG), to which IAEA participates and to which meetings IEEE and IEC are invited, prepared recommendations letters to those two standard organisations indicating its support to the already engaged collaboration to develop common dual logo standards both for new topics to be covered and for the revision of existing standards.

2. CORDEL Working Group[59]

The World Nuclear Association's (WNA) CORDEL Working Group was established with the aim of promoting the achievement of a worldwide regulatory environment where internationally accepted standardized reactor designs can be widely deployed without major design changes. Its membership consists of industry specialists in reactor licensing, nuclear law and reactor safety engineering, representing reactor vendor companies, utilities, technical support and consulting services and international organisations involved or directly interested in reactor licensing for new nuclear build.

The roadmap defined by CORDEL in 2010 described three steps, the last of which was "Issue international design certification", a procedure upon which a design could be certified by a team of national regulators so that participating countries would accept this certification. CORDEL also specifies that in that step, "national regulators would remain responsible for assessing the adaptation of the internationally certified design to the local circumstances and for the supervision of construction, commissioning and operation."[60]

3.5 Small Modular Reactors (SMRs)

There are currently four SMRs under construction in the world, three water cooled reactors (CAREM-25 in Argentina, KLT-40S and ABV-6M[61] in Russia) and one gas cooled reactor (HTR-PM in China).

The nuclear industry has been considering the deployment of commercial SMRs since the 1950s,[62] both to supply energy to communities with little access to other sources or to address the difficulties of financing a

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[56] In addition to what is presented here, the Western European Nuclear Regulators Association is working towards harmonising safety requirements. More information can be found at http://www.wenra.org/harmonisation/

[57] Extracted from: CEN-CENELEC, Report of Focus Group on nuclear energy. (2012).

[58] For more information, see http://www.oecd-nea.org/mdep/

[59] For more information, see http://www.world-nuclear.org

[60] Source: Cooperation in Reactor Design Evaluation and Licensing Working Group (CORDEL), Strategic Plan 2014-2018. (2014).

[61] The Russian models are floating power units.

large nuclear power plant. In recent years, with large new nuclear projects advancing more slowly than expected, costs rising above budget and an increased presence of intermittent sources in the energy mix and the progressive decentralization of the grid, opportunities in smaller scale nuclear power have become again under analysis.

There are several developments to design nuclear power plants in the power range up to 300 MWe, consisting of factory-built modules.

3.5.1 Design

The main designs for SMRs fall under three categories: light-water reactors (LWR), high-temperature gas cooled reactors (HTGR) and liquid-metal fast reactors (LMFR), with LWRs dominating in number amongst the designs that are most advanced.

Figure 14 Summary of the land-based SMR designs at most advanced stage of development[63]

Country	Design	Developer	Capacity (MWe)	Status
USA	NuScale (iPWR)	NuScale Power Inc	50	Preparing for Design Certification Application (note A)
	Westinghouse SMR (iPWR)	Westinghouse	225	Preparing for Design Certification Application (note B)
	Generation mPower (iPWR)	Babcock & Wilcox	180	Preparing for Design Certification Application (notes A and C)
China	HTR-PM (HTR)	Chinergy	105	Under construction, Shidaowan unit-1
	ACP100 (iPWR)	CNNC	100	Detailed Design, Construction starts in 2016
Argentina	CAREM (iPWR)	INVAP/CNEA	27	Under construction, near the Atucha-2 site
Russian Federation	SVBR-100 (LMFR)	AKME-engineering	100	License for placement of SVBR-100 in the Ulyanovsk region issued on 02/2015
Korea	SMART (iPWR)	KAERI	100	Standard Design Approval received 07/2012

Note A: Selected for US Government funding.
Note B: In January 2014 Westinghouse suspended all works on SMRs due to inadequate demand.
Note C: In early 2014 Babcock & Wilcox announced reduced spending due to lack of interest by investors and clients.

3.5.2 Characteristics

The IAEA defines as "small" those reactors with an electrical output lower than 300 MWe, and as "medium" those with an electrical output between 300 and 700 MWe.[64] Essential features of an SMR are modularity and integrated design.

Integrated design means that the reactor pressure vessel typically contains all primary components, such as the pressurizer, steam generators and reactor coolant pumps. Integrated design permits a modular construction of a NPP, as the reactor module can be manufactured in a separate factory, transported to the site by road or rail and erected on the site as a single block, with reduced construction time. In some designs the idea of modularity also means the 'splitting' of the power rating of one NPP unit to more than one standard module. Examples of this are provided by mPower, with its NPP consisting of two 180MWe modules, the HTR-PM with two 105 MWe modules and even more so, the NuScale project with its 12 modules of about 45 MWe each.

[62] Source: Ramana, M. (s.d.). The Forgotten History of Small Nuclear Reactors. Available at http://spectrum.ieee.org/energy/nuclear/the-forgotten-history-of-small-nuclear-reactors.

[63] Source: Joint Research Centre, Current Status of Small Modular Reactors (land-based). (2015)

[64] Source: International Atomic Energy Agency
https://www.iaea.org/NuclearPower/Downloadable/SMR/files/10_Clarification_on_the_use_of_SMR_terminology.pdf

Modularity together with smaller unit size allows more room for serial production, as more units will be needed to cover a given need for generation capacity.

Smaller unit sizes have other benefits that are linked to their impact in the electricity system. They allow responding gradually to increasing power demand, which is a positive effect due to the requirements that adding generation capacity puts on the power grid. Connecting a large new unit to the grid at a given point may require investing in strengthening the grid. Moreover, the required stand-by reserve capacity is likely to be higher for one large unit than for a number of smaller units with the same total generation capacity. Attention is also paid in SMR designs to the reactor being able to relatively rapidly respond to the changes in the required power output. Such improved load-following capacity could allow an SMR to complement an intermittent source of power.[65]

Smaller unit size also favors additional uses for nuclear energy, apart from power generation. It is easier to find suitable heat load for cogeneration, such as for district heating, for smaller power ratings.

Economics of SMRs compared to larger reactors

The unit cost of investment (investment per kW) is likely to be higher with SMRs than with larger units. The loss of economies of scale can be eventually balanced by standardization, learning effects, cost sharing and modularization, although these are difficult to quantify due to the lack of existing examples.

However, building multiple SMRs has some advantages when compared to building the same capacity in only one larger reactor:[66]

a) Protection against construction delays: Learning effect benefits would be more important due to the higher number of reactors to be built. In addition, the project can be split in different autonomous phases that limit the exposure to delays.
b) Better financial profile: due to the fact that construction periods are shorter for SMR, the incidence of financial costs is lower. With the deployment of SMRs, nuclear power could become more accessible for smaller power companies and for private financing.

Therefore, in uncertain scenarios the economics of SMR become more comparable to that of building large reactors. Nevertheless, the technology is not mature enough to further conclude on the economics, with cost estimates varying widely, amongst others depending on the country of construction. Estimates for overnight cost varying between 3 850 EUR/kWe and 7 750 EUR/kWe for one-unit 225 MW LWR plant have been reported,[67] while other estimates put investment cost (i.e. including interest) to the range 4 920–7 770 EUR/kWe.[68]

3.5.3 Safety and Licensing

Thanks to relatively low power density, SMRs can be designed largely relying on passive safety features. Residual heat after reactor shutdown can be dissipated without forced cooling, with long grace times, sometimes without operator intervention and for some design concepts with a very much reduced risk of core damage or radioactivity release. This could lead to improved safety through simpler design and higher reliability.

There are some areas where licensing requirements may put a burden to SMR when compared to larger reactors. The IAEA identified a number of "key issues in licensing and design certification" for SMRs,[69] e.g.

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[65] See David Shropshire, Arturs Purvins, Ioulia Papaioannou, Isabella Maschio, Benefits and cost implications from integrating small flexible nuclear reactors with off-shore wind farms in a virtual power plant. Joint Research Centre. (2012).

[66] Source: Ricotti, Sara Boarin and Marco E., An evaluation of SMR economic attractiveness. Science and technology of nuclear installations. (2014).

[67] Source: Joint Research Centre of the European Commission, Energy Technology Reference Indicator (ETRI) projections for 2010-2050. (2014).

[68] Source: National Nuclear Laboratory. Small Modular Reactors (SMR) – Feasibility Study. (2014).

[69] See https://www.iaea.org/NuclearPower/Downloadable/Meetings/2011/2011-03-28-04-01-TWG-NPTD/Day3/Issues-Challenges-SMR-Subki-20110330.pdf

viability of multiple-modules station, proliferation resistance and physical security, ergonomics and control room staffing, emergency planning zone or standardization and licenses for manufacturing and technology transfer and proprietary design protection.

SMRs using LWR technology are likely to have a shorter licensing process, as the technology is already proven and existing requirements are applicable. However, many SMR designs are novel with features that have not been deployed before, even in the case of LWR-designs. Examples include the integration of primary system components into the reactor pressure vessel and the use of passive recirculation modes with low coolant flows under operational and accident situations.[70]

Licensing will be more complex for SMRs with other technologies, such as HTGR and LMFR, where much more development work, testing and demonstration of safety systems will be needed. At least in the medium term, only designs at the low end of the 0-300 MW power range with a high degree of simplicity would be likely to deliver significant savings in licensing time and cost.

3.5.4 Cost of Decommissioning and Waste management

At the current stage of development it cannot be assessed whether the decommissioning and waste management costs of SMRs will significantly differ from those of larger reactors.

Due to the loss of economies of scale, the decommissioning and waste management unit costs of SMR will probably be higher than those of a large reactor (some analyses state that between two and three times higher).[71] On the other hand, the modular design is sometimes seen as a factor potentially helping to reduce the cost of decommissioning. It has been suggested that the reactor module could be transported from the site as one piece to a centralized factory for dismantling and recycling of components, thus lowering the overall cost. Such ideas are at least very far from becoming reality.

3.5.5 Future

The industry has historically favored the construction of large reactors looking for achieving economies of scale. Expected cost savings for SMRs due to modularity and standardized manufacturing would occur only when constructing a significant number of units. There is an opportunity to further investigate in this direction in the framework of a decentralized grid and as a complement of intermittent sources of energy. On the other hand, the absence of a licensed SMR design in the market is a major challenge. In the meantime, SMRs will be mostly used for testing innovative reactor designs and for attending niche markets.

3.6 Non-power applications

Five research/demonstrator reactors are being considered in the EU: MYRRHA[72] in Belgium, PALLAS in the Netherlands, ALFRED in Romania,[73] ASTRID in France[74] and ALLEGRO.[75] The total cost of developing these reactors is estimated to be in the range of EUR 8 to 9 billion, with some of them replacing aging installations (e.g. projects in Belgium and the Netherlands). In addition, there are projects already under construction such as a research reactor in France[76] and the upgrading of specific research reactors[77] for target irradiation destined to the production of medical radioisotopes.

[70] Source: see note 62.

[71] Source: Locatelli, G., Mancini, M, Journal of Engineering for Gas Turbines and Power, October 2010, Vol. 132.

[72] Multipurpose Hybrid Research Reactor for High-tech Applications.

[73] Advanced Lead Fast Reactor European Demonstrator.

[74] Advanced Sodium Technical Reactor for Industrial Demonstration.

[75] ALLEGRO is a Gas cooled fast demonstrator reactor. It is to be implemented in Hungary, Slovakia, Czech Republic or Poland.

[76] Jules Horowitz Reactor (JHR) is a 100MW boiling water reactor for research purposes being built in Cadarache, France. Construction is expected to be finished during 2016 and the total cost estimated in EUR 0,8 billion.

[77] Such as Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM II) in Munich, Germany.

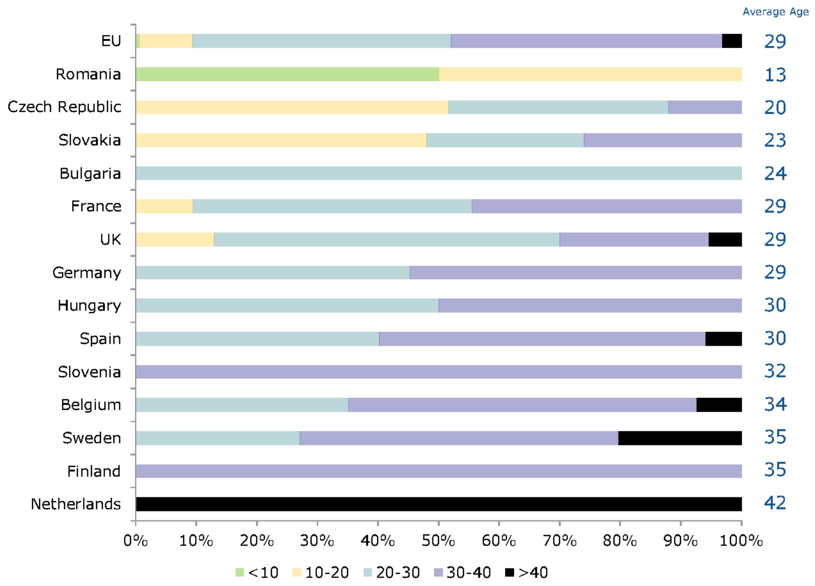
The Commission closely monitors developments related to radioisotope production in order to support reliable and secure supply, since the current capacity is fragile.[78]

Particular attention should be given to the operational sustainability of the only European supplier of research reactor fuel and uranium targets (AREVA-CERCA), which is now performing an investment in the order of EUR 0,14 billion in an in-depth safety upgrades of its plant in Romans (France).

4 Long term operations

The average operating age of the nuclear fleet in Europe is 29 years, whereas the approved operating life of individual reactors varies from 30 to 50 years.[79] When a nuclear power plant reaches the end of its approved lifetime, its license holder may request a lifetime extension from the regulator if the expected revenues from extending operations are bigger than the associated costs. The regulator will then assess this request based on safety considerations. This process is generally referred to as Long Term Operations, or LTO.[80] The decision on whether or not to grant life-time extensions of a nuclear power plant is taken by national authorities.

Figure 15 Age profile of the European nuclear power reactors[81]



4.1 Safety considerations

From a safety point of view, the responsible national authority will only grant permission for LTO following the operator's capacity to:

- Demonstrate and maintain plant conformity to its currently applicable regulatory requirements, and
- Enhance the plant safety as far as reasonably practicable.

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[78] For more information, see SWD(2015) 179 final, "Report on the Security of Supply of Radioisotopes for Medical Use and the Council Conclusions of 6 December 2010 and 7 December 2012 'Towards the Secure Supply of Radioisotopes for Medical Use in the European Union'".

[79] In some Member States the license is granted for an unlimited period of time subject to Periodic Safety Reviews at least every 10 years. Under this approach, it is admitted that the fourth safety review (40 years) is an important point in time where specific issues need to be considered, in particular ageing survey and feed-back.

[80] From IAEA Safety Report Series No 57: "Long term operation of a nuclear power plant may be defined as operation beyond an established time frame set forth by, for example, licence term, design, standards, licence and/or regulations, which has been justified by safety assessment, with consideration given to life limiting processes and features of systems, structures and components".

[81] Source: Internal analysis based on Power Reactor Information System (PRIS) database as of September 2015.

This implies that LTO programs always include safety upgrades, associated for example with modernisation or replacement of equipment such as instrumentation and control or the addition of back-up options (e.g. diesel generators). LTO programs generally also include the replacement of large components of the nuclear island (e.g. steam generators or the head of the reactor pressure vessel) as well as major refurbishments or replacements on the conventional islands (such as the turbo generator, the condenser or the transformers). Finally, LTO decisions are sometimes linked to achieving power uprates.

The Nuclear Safety Directive requires licence holders to systematically and regularly re-assess, under the supervision of the national regulator, the safety of nuclear installations specifically taking into account ageing issues. Therefore, Periodic Safety Reviews or Peer Reviews are performed regardless of LTO considerations. Potential decisions on lifetime extensions need to take such reviews into account.

Finally, extraordinary events or accidents can trigger a targeted response including specific additional plant modifications. This is the case after the Fukushima Daiichi accident.

Box 4 Influence of the Fukushima accident

The challenges faced in the field of nuclear safety and its governance were highlighted in the accident at the Fukushima reactors in Japan following the earthquake and the tsunami in March 2011. The accident resulted in unprecedented efforts to review the safety of nuclear installations in Europe and worldwide, with initiatives taken at national, regional and international level.

All countries with operating NPPs have already started implementing the lessons learnt and will continue to do so within their regulatory systems on a continuous basis, since the completion of the overall assessment of this accident may take several years. These include significant actions to increase robustness of plants, as presented during the two European Nuclear Safety Regulators Group (ENSREG) National Action Plan Workshops which were held in Brussels in 2013 and 2015.[82] For example: provisions of additional mobile equipment to prevent or mitigate severe accidents, installation of hardened fixed equipment and the improvement of severe accident management, together with appropriate staff training measures.

Based on the information available from different sources, the cost of some major safety upgrades implemented on EU NPPs before or just after Fukushima can be estimated. For example, for Light Water Reactors it can be quantified in the range between EUR 35 to EUR 140 million per unit depending of the necessary safety upgrades to be implemented. These may include:

- Additional seismic investigations of NPP sites and assurance of seismic resistance of equipment, piping, buildings and structures important to safety.
- Improved protection against external events;
- Provision of (additional) alternative electrical power supplies
- Autonomous power supply for the safety valves of the pressuriser
- Provision of alternative heat sink for the reactor and the Spent Fuel Pool
- Hydrogen concentration monitoring system in containment
- Installation of Passive Autocatalytic hydrogen Recombiners (PARs)
- Installation of Filtered Containment Venting System (FCVS)
- Provision of additional portable or fixed equipment (pumps, Diesel Generators, etc.)
- Plant modifications for In Vessel or Ex Vessel corium retention
- Accident monitoring system
- New bunkered Emergency Control Room
- Hardened safety core (FARN, for "Nuclear Rapid Action Force", mobile DGs and other systems)

Compared to the cost considered for a typical LTO program, the post-Fukushima measures represent an increased cost of 5 to 25 %.

4.2 Economic considerations

Extending the useful life of a reactor is generally more attractive for the operator compared to building a new facility since it generally means a lower capital investment.

Based on data publically available and on questionnaires addressed to the nuclear power plant operators, an overview of LTO associated costs is presented in Figure 16. However, it is not always easy to distinguish which upgrades or modernisation measures are directly linked to LTO programs and which are linked to normal operation and periodic safety review of the plant.

[82] The summary reports of these two workshops were endorsed by ENSREG and made public on the ENSREG website (http://www.ensreg.eu/EU-Stress-Tests/Follow-up).

Figure 16 LTO and post Fukushima safety investments from 2000 to 2025 (EUR/kWe)[83]

Country	LTO investment	Post Fukushima investments
Median	**571**	**34**
Average	**629**	**63**

Note: only median and average figures disclosed for confidentiality reasons

4.3 Estimated investments in LTO for the period 2015-2050

Considering the projected evolution of the currently operational nuclear capacity that will operate beyond its original lifetime (see Figure 17)[84] and the costs calculated in the previous section, the estimated investment needs in LTO for the period 2015-2050 are EUR 46,9 billion (see Figure 18).

Figure 17 Projected evolution of the existing fleet (GW)

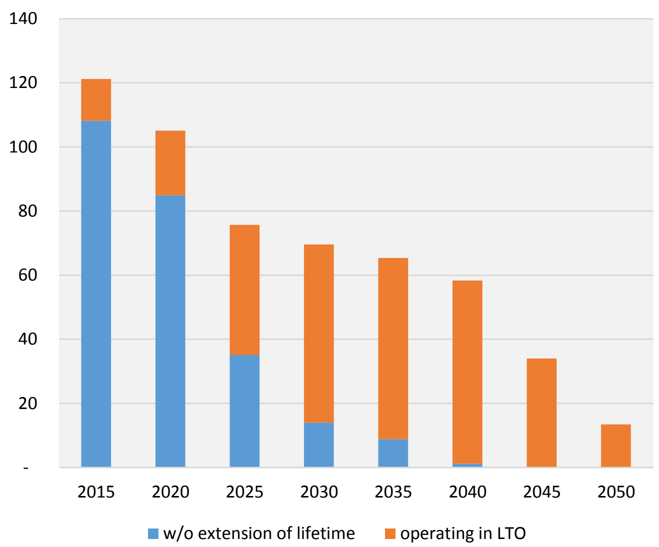


Figure 18 Estimated investment needs in LTO

	2015-2030	2031-2040	2041-2050	Total
EUR billion	38,1	8,5	0,3	46,9

Box 5 The case of France

There are 36 reactors in France that have been operating for more than 30 years, with a combined capacity of 34 GW. The French regulation does not foresee pre-defined operating licenses, but rather establishes comprehensive periodic safety assessment processes undertaken every 10 years,[85] under the control of French Safety Authority (ASN). The results of these assessments, together with the correspondent profitability analysis carried out by the operator, will define the number of reactors that will be operating in LTO. The ASN has stated that potential requests for extending the lifetimes over 40 years of operation will be reviewed in the light of the safety objectives for new reactors such as the EPR.[86]

[83] Figures reported are the average of the Member State's NPPs reactors considered and have been converted to match a "representative" 1 000 MWe Nuclear Power Plant and 20 years LTO program for comparability purposes. Source: Questionnaires sent by the Commission to the EU NPP operators in June 2015.

[84] Projecting the number of reactors that will be granted with lifetime extensions is subject to significant uncertainties, as described in note 47.

[85] Law on transparency and nuclear energy safety (TSN) of 13 June 2006.

[86] Source: http://www.asn.fr/L-ASN/Appuis-techniques-de-l-ASN/Les-groupes-permanents-d-experts/Groupe-permanent-d-experts-pour-les-reacteurs-nucleaires-GPR/Seance-des-18-et-19-janvier-2012

The "Energy transition for green growth act" adopted by the French Parliament in August 2015[87] defines as one of its objectives the reduction of the nuclear energy contribution to the production of electricity to 50 % (from 74 % today).[88] It also proposes a ceiling to nuclear installed capacity at the current level (63,2 GW).

Title VI of the ""Energy transition for green growth act" foresees the creation of a "stricter regulatory framework for the continued operation of nuclear facilities that are over 40 years old."

Implementing measures of the law are not completely defined yet. The projections presented in this Staff Working Document consider that the reduction in nuclear electricity will be achieved in line with the law (projecting that 52 % of the electricity production in 2025 will come from nuclear plants). The projection further assumes that the share of nuclear energy in the electricity mix remains stable at 50 % and considers NPPs load factors at 80 %. Consequently, the reduction in electricity production from current levels occurs via shut-down of some of the existing reactors at the end of their operating life. An alternative scenario where more reactors remain in LTO while their load factor is significantly reduced has not been considered, since their profitability would be severely impacted probably leading to their closure for commercial reasons.

5 The back-end of the nuclear fuel cycle

The back-end of the nuclear fuel cycle encompasses all the activities following the irradiation in the reactor, which differ depending on whether or not the irradiated fuel is reprocessed and the nuclear material is recycled. These activities are divided into waste management and decommissioning, although both of them are highly interconnected. Decommissioning refers to all administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a facility. Waste management refers to all administrative and operational activities involved in the handling, pre-treatment, treatment, conditioning, transport, storage and disposal of radioactive waste.

5.1 Waste management

Radioactive waste is defined as material for which no further use is foreseen that contains a level of radioactivity greater than clearance levels as established by the competent regulatory authority. Although the exact specifications vary among Member States, these typically exclude material and waste with very low concentrations of radionuclides and those that contain only ‘natural’ concentrations of naturally occurring radionuclides.

In general, radioactive waste is classified according to two criteria:[89]

- its level of radioactivity, measured in Becquerel. A distinction is made between high-level (HLW), intermediate-level (ILW), low-level (LLW) and very low-level waste (VLLW)

- its lifespan, which corresponds to the rate of radioactive decay over time. Waste is classified based on the half-live of the elements, i.e. the period of time necessary for their radioactivity to be halved. A distinction is made between very short-lived waste (less than 100 days), short-lived waste (half-live of 30 years or less) and long-lived waste (half-live over 30 years).

In the EU, some 122 000 m3 of radioactive waste is generated each year.[90] The vast majority of this radioactive waste originates from day-to-day activities at NPPs and other nuclear installations and is classified as low-level and short-lived, for which waste management strategies are implemented on industrial scale in nearly all EU Member States with a nuclear power programme.

Figure 19 Classification of radioactive waste[91]

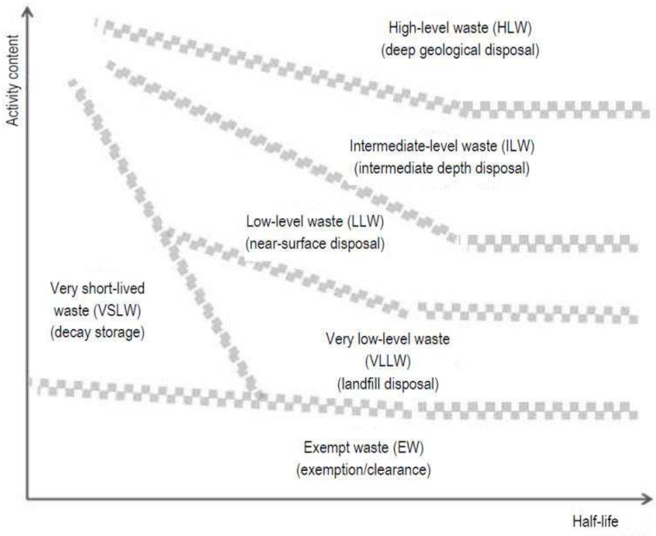
[87] For more information, see http://www.developpement-durable.gouv.fr/IMG/pdf/joe_20150818_0189_0001_1_.pdf

[88] Source: Eurostat.

[89] Source: French Court of Auditors, The costs of the nuclear power sector. Thematic public report. (2012).

[90] Source: Internal data.

[91] Source: International Atomic Energy Agency, Classification of Radioactive Waste. (2009).



5.1.1 High level waste (HLW)

High level waste includes the radioactive liquid containing most of the fission products and actinides present in spent fuel and some of the associated waste streams; this material following solidification; spent fuel (if it is declared as waste); or any other waste with similar radiological characteristics.[92]

Typical characteristics of high level waste are concentrations of long lived radionuclides exceeding the limitations for short lived waste. This is waste with levels of activity concentration high enough to generate significant quantities of heat by the radioactive decay process or waste with large amounts of long lived radionuclides that need to be considered in the design of a disposal facility for such high level waste. Disposal in deep, stable geological formations is the generally recognized option for the disposal of high level waste.

Around 3 200 tons of heavy metal (tHM) of spent nuclear fuel is generated every year, together with approximately 200 m^3 of high-level waste. As of the end of 2010, there were about 53 300 tHM (mostly uranium) in spent fuel in storage in the EU, most of it at reactor sites.

Fuel cycle policy

Choosing the ‘closed’ or ‘open’ fuel cycle is a matter of national policy, the difference being in how spent fuel is viewed – either as waste (open cycle) or a resource to be used further (closed cycle). Only a few Member States have consistently committed to implementing either an open or closed fuel cycle. The open cycle strategy has been adopted by Sweden and Finland, where the encapsulated fuel is planned to be disposed of in a geological repository after 40 years interim storage. Also in Germany the open fuel cycle is currently used, resulting from a 2002 amendment of the nuclear energy act (subsequently, in 2011, a decision was taken to phase-out nuclear power). On the other hand, France is working towards a fully closed fuel cycle with the development of fast neutron reactors and advanced reprocessing technology to recycle fissile materials.[93]

5.1.1.1 Open cycle

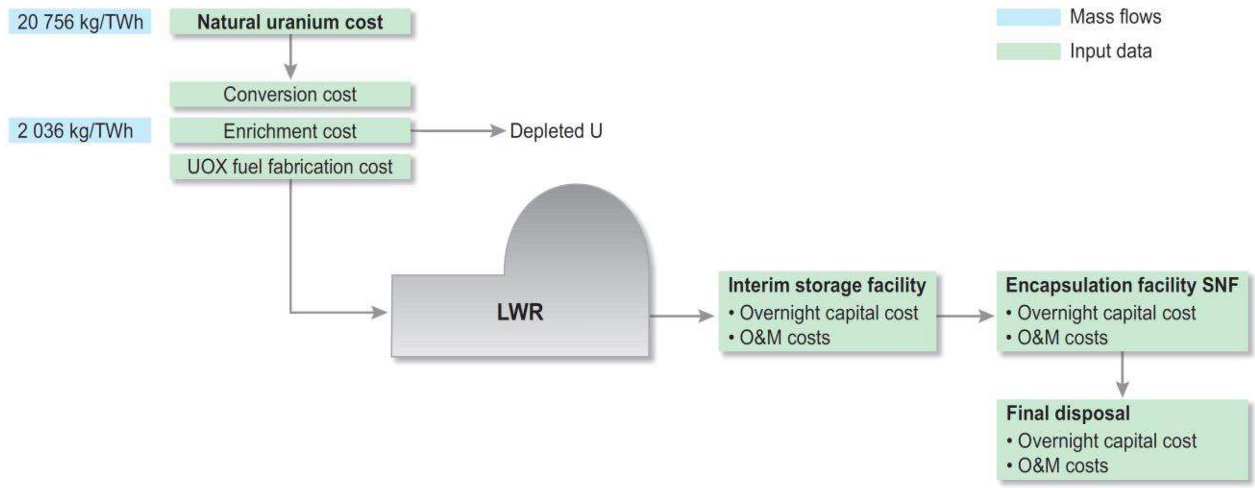
In the once-through or open cycle, the spent nuclear is directly disposed. The activities involved in this option are the following:

1. interim storage of the spent fuel in the reactor pools for some years for the fuel to cool down by decay of short-lived radionuclides;
2. if needed, transfer to a dedicated store at the reactor site or to a centralised storage facility. Spent fuel can be stored in pools (‘wet storage’) or in casks in a dedicated facility (‘dry storage’).
3. encapsulation of the fuel in a disposal container; and
4. disposal in a final repository.

[92] Source: International Atomic Energy Agency, Safety Glossary, Draft 2016 Revision. (2015). (IAEA , 2015)

[93] Source: European Academies’ Science Advisory Council, Management of spent nuclear fuel and its waste. (2014).

Figure 20 Illustrative once-through (OT) cycle[94]



5.1.1.2 (Partially) closed cycle

In a "closed" fuel cycle the spent fuel is recycled by extracting the main fissile components (plutonium and uranium). This process involves the following activities:

1. interim storage of the spent fuel in the reactor pools for some years for the fuel to cool down by decay of short-lived radionuclides; transfer of the fuel to a reprocessing plant;
2. conditioning of the waste products (HLW) e.g. by vitrification, and transfer of the conditioned waste to a facility for interim storage, pending disposal;
3. reuse of the recovered plutonium and uranium for the fabrication of recycled fuel with the recovered plutonium and uranium in dedicated plants and re-use of these fuels in a thermal neutron reactor or in a fast neutron reactor; and
4. disposal of all the HLW and other long-lived radioactive waste in a final repository.

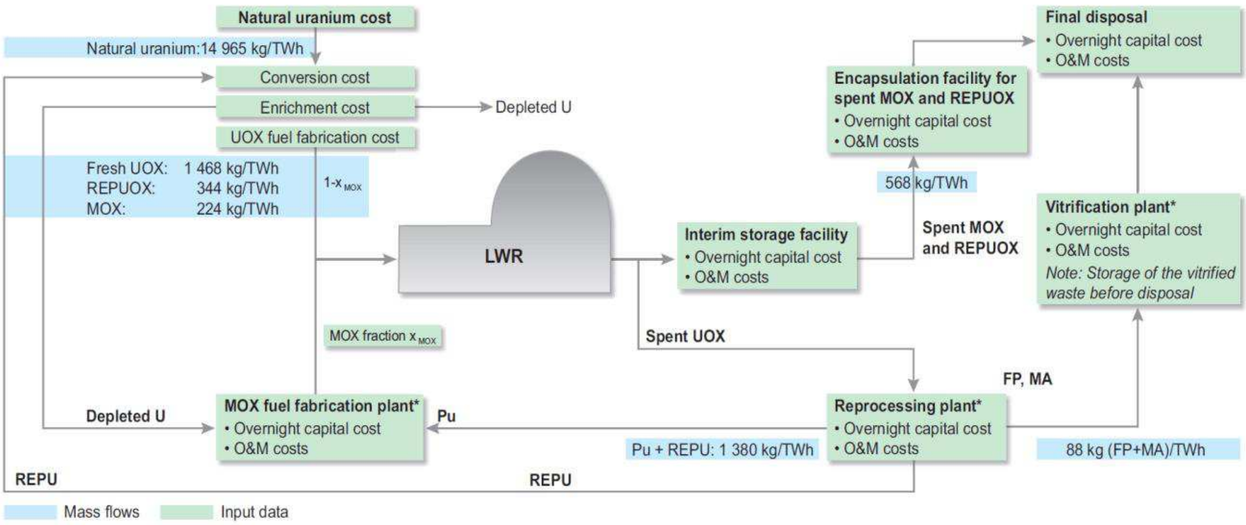
Full recycling remains for the moment a long term prospect and is in principle only feasible with the use of fast neutron reactors, which can be optimised to consume the plutonium and uranium efficiently and/or to incinerate long-lived minor actinides. Due to several uncertainties around the deployment of this type of reactors, including their high capital costs, the possibility of closing the fuel cycle has not been foreseen in this Staff Working Document.

Since the technology for fast-breeder reactors is not currently deployed in the EU, countries that considered the closed fuel cycle turned to a 'partially closed cycle' where plutonium is recycled in MOX fuel that is then loaded into nuclear reactors. Spent MOX is currently intended for disposal, although it could be further recycled.

Figure 21 Illustrative PWR-MOX recycling cycle[95]

[94] Source: see note 4.

[95] Source: see note 4. Notes: UOX: Uranium Oxide. REPU: Reprocessed Uranium. REPUOX: Reprocessed Uranium Oxide.



5.1.1.3 Overview of existing spent fuel policies

In 2014, MOX fuel was used in a number of reactors in Germany, France and the Netherlands. In other Member States the situation has varied over the years: fuel has been reprocessed and partially recycled and direct disposal is envisaged, at least for part of the fuel.

A list of the commercial reprocessing facilities is presented in Figure 22, with only France and the United Kingdom operating facilities at the moment. Belgium, Germany, Italy, Japan, Spain and Sweden have been customers of France’s reprocessing services (with Spain being a former customer of UK's services as well), while the Netherlands still is. The Czech Republic, Slovakia, Germany, Finland and Hungary are former customers of the reprocessing services provided by Russian/Soviet facilities, whereas Bulgaria continues to send spent fuel to Russia for reprocessing.[96]

Figure 22 Commercial reprocessing facilities in Europe[97]

Country	Facility Name	Status	Scale	Start of Operation	End of Operation
BE	Eurochemic	Decommissioning	60 t HM/year	1966	1975
FR	Areva NC La Hague - UP2-400	Decommissioning	400 t HM/year	1966	2004
FR	Areva NC La Hague - UP2-800	In operation	1 000 t HM/year	1996	
FR	Areva NC La Hague - UP3	In operation	1 000 t HM/year	1990	
FR	Marcoule - UP1	Decommissioning	600 t HM/year	1958	1997
DE	Karlsruhe Reprocessing Plant	Decommissioned	35 t HM/year	1971	1991
IT	Eurex SFRE (Oxide – pilot plant)	Decommissioning	10 t HM/year	1980	1990
UK	NDA Magnox Reprocessing	In operation	1 500 t HM/year	1964	2018
UK	NDA Thorp	In operation	900 t HM/year	1994	2018

[96] Source: International Panel on Fissile Materials, Plutonium separation in nuclear power programs. (2015).

[97] Source: webpage of the Nuclear fuel cycle information system, accessed on 22/10/2015.

In the international context, the United States follows the policy to pursue centralised interim storage[98] and ultimate disposal for the current inventory of spent nuclear fuel without further treatment. However, a Mixed Oxide Fuel Fabrication Facility is being built in by a consortium including AREVA. The main objective of this facility is the reduction of weapon-grade plutonium stocks. The latest cost estimate is EUR 18 billion.[99] The facility will have a recycling capacity of 3,5 tons of plutonium into MOX each year. Japan, Russia, India and China also have commercial or pilot reprocessing facilities.

Factors affecting the choice of a nuclear fuel cycle strategy

The choice between an open cycle or a recycling strategy is made in each case by the individual Member State based on diverse considerations, among which some of the most relevant are the following:

a) Sustainability – Reprocessing spent fuel optimizes the existing reserves of uranium and contributes to the security of supply dimension, since it replaces uranium that otherwise would have to be imported from outside the EU. In 2014, savings in natural uranium due to the use of MOX fuel represented 6.8% of the total uranium loaded into European reactors, as shown in Figure 4. Moreover, interim storage of the irradiated MOX assemblies can further constitute a reserve of plutonium to feed fast-breeder reactors in the future.[100]
b) Radioactive waste management - The Spent Fuel and Radioactive Waste Management Directive considers both strategies (direct disposal and reprocessing) as possible options. Reprocessing reduces the volumes of high-level waste and therefore the size of the spent fuel storing facilities needed. Nevertheless, whatever choice is made, there will be always be a need to build a final disposal repository, albeit at a significantly smaller scale if the fuel is recycled.[101]
c) Non-proliferation – The use of nuclear materials for solely civil purposes is controlled worldwide by the application of IAEA safeguards, acting under the Non-Proliferation Treaty. Within the EU, the control is complemented by Euratom Safeguards that verify the declared uses of nuclear materials. A reprocessing strategy has to be accompanied by appropriate safeguards arrangements which take into account the plutonium separation facilities.[102]
d) Economics – Cost estimations are subject to several uncertainties such as the price of uranium and the schedule for building a final disposal facility. Other important parameter that influences the economics of the back-end of the nuclear fuel cycle is the size of the nuclear fleet, reflecting economies of scale and the fact that spent fuel management in a Member State with few reactors would differ significantly from the case of a very large nuclear programme with tens of reactors.[103]

With the decision of the United Kingdom of shutting down their reprocessing facilities in 2018, France is the only Member State with a decided industrial policy towards recycling. A number of other Member States are still deliberating.

5.1.1.4 Final disposal facility

Regardless of the fuel cycle strategy chosen, it is acknowledged that in the long term Member States with nuclear capabilities will be required to find a permanent solution for the HLW/ Spent Fuel generated. The construction of a geological repository is the commonly accepted option. The Waste Isolation Pilot Plant in

[98] Source: U.S. Department of Energy's Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste.

[99] Source: Platts Nuclear News Flashes. 20/08/2015.

[100] Nevertheless, at the current rate of consumption existing resources of uranium are considered to be sufficient to support the continued use of nuclear power (the identified resource base would be sufficient for over 150 years of supply). See: OECD Nuclear Energy Agency and International Atomic Energy Agency, Uranium 2014: resources, production and demand. (2014).

[101] In addition to volume considerations, other relevant factors to compare the different scenarios include decay heat and radio-toxicity. See: Massachusetts Institute of Technology, The future of the nuclear fuel cycle. (2011).

[102] Source: Massachusetts Institute of Technology, The future of nuclear power. (2009).

[103] Source: see note 4.

Carlsbad, New Mexico, USA, is the only geological facility for HLW[104] functioning in the world (in operation since 1999 to dispose of waste produced in the US nuclear defence programme)[105]. No civil deep geological repository has yet been built yet.[106] In Europe, Finland,[107] Sweden and France have the most advanced programmes, with most of the other Member States having no plans of starting the construction in the short-term. Meanwhile, long term storage facilities are being built for a lower cost, although these are not substitutes of the geological facility.

Developing a deep geological repository offers possibilities of cooperation between Member States and research programs are being conducted at European level. The "Implementing Geological Disposal Technology Platform (IGD-TP)"[108] plays an important role in this regard. Regional initiatives to share the costs are also possible (for example, Croatia and Slovenia share the ownership of the Krško NPP and will have to coordinate their approach to dispose the spent fuel).

Figure 23 Status of the projects to build geological repositories to dispose HLW[109]

Member State	Status	Planned start of operations	Estimated cost[110] (EUR billion)
BE[111]	Preliminary studies	Not disclosed	3,2
BG	Preliminary studies	Not disclosed	
CZ	Preliminary studies	2065	4,5
DE	Preliminary studies	2050	10,0 (note A)
ES[112]	Preliminary studies	2062	Not disclosed
FI	Construction license granted	2020	3,6
FR[113]	Stakeholders consultation	2025	25,9
HR	Preliminary studies	Not disclosed	0,4
HU	Site selection	2064	2,4
IT	Preliminary studies	Not disclosed	2,5
LT	Preliminary studies	2066	2,6
NL	Preliminary studies	2130	Not disclosed

[104] The HLW in this facility differs to the HLW produced in the civil cycle – i.e. vitrified heat-generating waste –, since it rather corresponds to materials contaminated with transuranics.

[105] Source: webpage of the US Department of Energy (http://www.wipp.energy.gov/wipprecovery/about.html) accessed on 22/10/2015.

[106] Source: see note 4.

[107] The Finnish government granted a construction license to Posiva for a spent fuel repository on November 2015. The facility is expected to be completed by 2023. Source: Platts Nuclear News Flashes, 12/11/2015.

[108] The IGD-TP technology platform was set up in 2009 with the aim of better targeting research, development and demonstration (RD&D) programmes and ensuring improved research between Member States. Its role is to boost confidence in the safety and implementation of radioactive waste disposal solutions in deep geological formations.

[109] Source: National reports under Council Directive 2011/70/Euratom unless otherwise specified.

[110] Figures include operational and decommissioning costs.

[111] There is no national policy concerning geological disposal in Belgium. The estimated costs were obtained from: ONDRAF/NIRAS, Cost evaluation of geological disposal of category B&C waste for the long term fund. (2013).

[112] Source: Spanish Court of Auditors, Informe Nº 1075. (2015).

[113] Note: On 15 January 2016 the French Ministry of Ecology, Sustainable Development and Energy issued a Ministerial Order updating the cost associated with the implementation of the long-term management solutions for long-lived medium and high-level radioactive waste related to the Cigéo project at EUR 25 billion under 2011 economic conditions.

Member State	Status	Planned start of operations	Estimated cost[110] (EUR billion)
PL	Preliminary studies	Not disclosed	
RO	Preliminary studies	2050	2,2
SE	Construction license requested	2028	3,2
SI[114]	Preliminary studies	2065	0,4
SK	Preliminary studies	2065	3,7
UK	Preliminary studies	2075	13,1
TOTAL			**77,7**

Note A: includes the estimated total investment in Morsleben and Gorleben diposal facilities.

5.2 Decommissioning of nuclear power plants

The decommissioning of nuclear power plants will become an increasingly important activity for the European nuclear industry in the coming years due to the ageing of the fleet. However, experience in this field is rather limited. There were 90 power reactors shut-down in the EU as of January 2016, but only three of them have been completely decommissioned (all in Germany). The international perspective does not provide much more experience: although there are 147 reactors in shutdown mode worldwide, only 13 have been completely decommissioned in addition to the three mentioned in Europe, all of them in the United States. France, Germany and the United Kingdom account for 78% of the nuclear power reactors in shutdown mode in Europe.

Figure 24 Nuclear reactors in shut down status per MS and technology[115]

	BWR	FBR	GCR	HTGR	HWGCR	LWGR	PHWR	PWR	SGHWR	Total
BE										
BG								4		4
DE	9	1		2	1		1	14		28
ES	1		1					1		3
FR		2	8		1			1		12
IT	2		1					1		4
LT						2				2
NL	1									1
SE	2						1			3
SK					1			2		3
UK		2	27						1	30
Total	**15**	**5**	**37**	**2**	**3**	**2**	**2**	**23**	**1**	**90**

[114] The National Program did not disclose the estimated costs. We have used the information provided by the Croatian party, since the ownership of the NPP is shared at 50/50.

[115] Source: Power Reactor Information System (PRIS) consulted on January 2016. The list includes experimental reactors.

BWR - boiling water reactor, FBR – fast-breeder reactor, HTGR - high temperature gas cooled graphite moderated reactor, GCR - gas cooled reactor, HWGCR - heavy water moderated gas cooled reactor, LWGR - light water cooled graphite moderated reactor, PHWR - pressurized heavy water reactor, PWR - pressurized water reactor, SGHWR - steam generating heavy water reactor.

The significance of the decommissioning activities when compared to the full nuclear fuel cycle costs depends of the temporal perspective. The illustrative calculation presented in Figure 25 shows the impact of the decommissioning costs per kWh of electricity produced by a generic nuclear power plant throughout its operating life.

Figure 25 Illustrative calculation of the decommissioning costs in relation to the price of electricity sold[116]

Overnight Construction Costs (EUR million)	Decommisioning costs		Estimated production GWh (B)	Decommissioning costs in EUR per kWh produced = A/B	Decommissioning costs as % of electricity prices
	Estimate	EUR million (A)			
8 500	15%	1 275	702 202	0,0018	4%

Estimations of the costs of decommissioning commercial nuclear power reactors vary significantly between Member States, technologies, size and location of the reactor and dismantling strategy chosen. Given the ageing status of the European reactors, the capability of the industry and the regulators to develop safe and cost effective decommissioning programs will affect the future of the nuclear commercial power in Europe. This includes greater transparency in cost estimates and further collaboration between Member States to identify best practices.

Several international projects have been recently undertaken in order to provide more clarity on decommissioning cost estimations, such as the joint IAEA/EC/NEA project on the "International Structure for Decommissioning Costing (ISDC) for Nuclear Installations", or the publications by the Radioactive Waste Management Committee (RWMC) of the Nuclear Energy Agency (NEA).

5.2.1 Decommissioning strategies

According to the IAEA Safety Standards,[117] there are two possible decommissioning strategies:

1) **Immediate Dismantling**: decommissioning actions begin shortly after the permanent shutdown of operation. Equipment and structures, systems and components of a facility containing radioactive material are removed and/or decontaminated to a level that permits the facility to be released from regulatory control for unrestricted use, or released with restrictions on its future use. This strategy has the main advantage that personnel involved in the operating phase is available, providing a good knowledge of the plant history. In addition, the site may become available for future use and this strategy is normally better accepted in the public opinion. On the other hand, it requires the use of interim storage facilities (if no final disposal facility is available) and levels of radioactivity in the reactor are higher than in the case of deferred dismantling. This means that greater precautions must be taken during dismantling and that larger volumes of decommissioning waste will be classified as radioactive. This strategy also requires an earlier disbursement of cash.
2) **Long Term Safe Enclosure** (deferred dismantling): after removal of the nuclear fuel from the facility, all or part of a facility containing radioactive material is either processed or placed in such a condition that it can be put in safe storage and the facility maintained until it is subsequently decontaminated and/or dismantled. This strategy may involve early dismantling of some parts of the facility and early processing of some radioactive material and its removal from the facility, as preparatory steps for the safe storage of the remaining parts. Time provides the advantage of reducing the radioactivity, which makes the decommissioning works easier, and of postponing the cash disbursements. However, there is an impact on the available knowledge of the plant that may be irreversible.

Entombment, in which all or part of the facility is encased in a structurally long lived material, is not considered a decommissioning strategy and is not an option in the case of planned permanent shutdown. It

[116] Source: Internal calculation. Overnight Construction Cost (OCC) obtained from the high-range disclosed in section 3.1.1of this report. Estimation of decommissioning costs as % of OCC obtained from Nuclear Energy Agency, Projected Costs of Generating Electricity, (2015). Production of the NPP calculated as follows: 1 670 MWe x 24 hours x 365 days x 60 years x 80% availability factor. Average wholesale baseload electricity price in France for the first quarter of 2015 was 45,1 EUR/MWh - Source: (Market Observatory for Energy - DG ENER, 2015).

[117] International Atomic Energy Agency, Decommissioning of Facilities, General Safety Requirements No. GSR Part 6. (2014).

may be considered a solution only under exceptional circumstances (e.g. following a severe accident). Immediate decommissioning is the preferred strategy indicated by the IAEA Safety Standards. It is also in line with the objectives of the Radioactive Waste Management Directive:[118] "It should be an ethical obligation of each Member State to avoid any undue burden on future generations in respect of spent fuel and radioactive waste including any radioactive waste expected from decommissioning of existing nuclear installations". However, there may be situations in which immediate dismantling is not a practicable strategy when all relevant factors are considered.

Figure 26 Decommissioning strategies[119]

Immediate dismantling	Deferred dismantling	No preferred option
Belgium Bulgaria Spain Finland (Loviisa) France Croatia Italy (Note A) Lithuania Netherlands (Borssele) Sweden Slovenia Slovakia (Note B)	Finland (Olkiluoto) Hungary Netherlands (Dodewaard) Romania United Kingdom	Czech Republic Germany

Note A Italian NPPs have been formally under an operating mode status for many years after stopping producing electricity.
Note B Decommissioning plans for JE V2 have not been decided and consider both options as possible. Source: (Slovakian National Nuclear Fund, 2014).

5.3 Financing the back-end activities

Most of the cash disbursements related to waste management and decommissioning activities will occur once the related nuclear power plant has stopped generating revenues. To ensure that there will be enough funds to pay for back-end activities, regulators require nuclear licensees to set up funds which are built up during the plant operation. Nuclear operators are also deemed to be compliant with International Accounting Standards (IAS), under which provisions for one-off events (such as environmental clean-up) are measured at the most likely amount [IAS 37.40].

In most Member States, nuclear regulators specifically define the method for constituting and securing decommissioning and waste management funds. In other cases, the regulator refers to the accounting principles and commercial law and does not require additional funding measures.[120]

5.3.1 Estimation of the total charges

An adequate coverage of the funding needs is based on an accurate estimation of what the decommissioning and waste management costs will be. This estimation is affected by several uncertainties that have already been described in this report, linked for example to the lack of experience in the field. Early closures or extensions of the operating lifetimes of nuclear plants have also a significant effect.

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[118] OJ L199, 2.8.2011, p. 48.

[119] Source: Responses submitted by members of the Decommissioning Funding Group to the questionnaires designed to update information on individual Member States alignment to the Commission Recommendation (2006/851/Euratom) on the management of financial resources for the decommissioning of nuclear installations, spent fuel and radioactive waste, except the cases of the UK, where information was obtained from public sources available at the Nuclear Decommissioning Authority webpage and Finland, where information was complemented with the National Program referred in note 122. Note: not all Member States have issued a National decommissioning strategy. For those cases, we have reflected the expected/ preferred strategy, if any.

[120] As it is the case in Germany. However, the government has asked a commission to make recommendations on how to safeguard the funding of the decommissioning by the end of February 2016. A public trust, which would safeguard the nearly EUR 40 billion in provisions set aside so far by the utilities, is one option under discussion.

All national bodies exercise periodic controls of decommissioning costs estimates. The frequency of checks is at least every five years, while often there are more frequent controls.[121]

Decommissioning estimates per unit vary within Member States, as can be seen in Figure 27. However, a direct comparison is misleading because they relate to several technologies, are frequently reported under a different scope of activities and there are different regulatory regimes. Moreover, these estimations refer to future payments only, which has to be considered when comparing Member States where significant decommissioning funds have already been disbursed to others where the bulk of the decommissioning activities will occur in the future. Estimates should therefore be reviewed on a case-by-case basis.

Figure 27 Estimated costs of decommissioning NPPs[122]

MS	Estimated Decommissioning costs (EUR billion, note A)	Total NPPs			Estimated cost of decommissioning (EUR billion per unit)	Estimated cost of decommissioning (EUR billion per GWe)
		Units	Capacity (MWe)	Average capacity		
BE[123]	4,6	7	5 921	846	0,7	0,8
BG[124]	2,3	6	3 558	593	0,4	0,6
CZ	1,5	6	3 904	651	0,3	0,4
DE	34,0 (note B)	36	26 375	733	0,9	1,3
ES	4,5	10	8 188	819	0,5	0,5
FI[125]	1,0	4	2 752	688	0,3	0,4
FR	22,6	70	66 919	956	0,3	0,3
HR	0,2	0,5 (note C)	344	344	0,3	0,4
HU	1,2	4	1 889	472	0,3	0,6
IT	3,9	4	1 423	356	1,0	2,7
LT	1,4	2	2 370	1 185	0,7	0,6
NL	0,5	2	537	269	0,3	0,9
RO[126]	1,4	2	1 300	650	0,7	1,1
SE	3,4	13	10 861	835	0,3	0,3
SI[127]	0,2	0,5 (note C)	344	344	0,3	0,4

[121] COM(2013) 121 final, Use of financial resources earmarked for the decommissioning of nuclear installations, spent fuel and radioactive waste.

[122] Sources: Responses submitted by members of the Decommissioning Funding Group (DFG) to the questionnaires designed to update information on individual Member States alignment to the Commission Recommendation (2006/851/Euratom) on the management of financial resources for the decommissioning of nuclear installations, spent fuel and radioactive waste, unless otherwise specified. Power Reactor Information System accessed on October 2015.

[123] The response submitted by the member of the DFG corresponded to the provisions registered by the operator as of December 2014 (measured in net present value). The figure reported in this SWD was provided by the Belgian Ministry of Economy following the publication of the draft PINC.

[124] The response submitted by the member of the DFG did not include the estimated costs of decommissioning Blocks 5 and 6 of the Kozloduy NPP. These are estimated in EUR 1,9 billion at the "Revised strategy for spent nuclear fuel and radioactive waste management" approved by the Council of Ministers on 2 September 2015.

[125] Figure obtained from the National Program submitted under Directive 2011/70/Euratom.

[126] See note 125.

[127] The DFG did not provide any figure. It has been considered to be the same amount as the one reported in the HR questionnaire.

MS	Estimated Decommissioning costs (EUR billion, note A)	Total NPPs Units	Capacity (MWe)	Average capacity	Estimated cost of decommissioning (EUR billion per unit)	Estimated cost of decommissioning (EUR billion per GWe)
SK[128]	3,1	9	3 665	407	0,3	0,8
UK[129]	36,9	45	13 598	302	0,8	2,7
Totals	**122,7**	**221**	**153 948**	**697**	**0,6**	**0,8**

Note A: Considering reactors currently in operation and in shut-down mode. Reactors under construction have only been included in the estimation from Slovakia (Mochovce EMO1/2).
Note B: Includes estimation of waste management costs, excluding the final disposal facility. Figure obtained from the National Program submitted under Directive 2011/70/Euratom.
Note C: Croatia and Slovenia share ownership of the Krško Nuclear Power Plant.

Waste management estimates also show discrepancies between Member States, mainly due to the significant uncertainties existing around the costs of building a final disposal facility. A summary is presented in Figure 28. The average result of 3,2 EUR per MWh is higher than what was estimated in recent studies (in the level of 1,5 EUR per MWh).[130]

Figure 28 Waste management estimates reported by Member States (including costs for the building of geological repositories)[131]

MS	Estimated Waste Management costs (EUR billion)	Lifetime electricity supplied from NPPs [TWh] Average lifetime load factor[132]	Actual electricity supplied as of Sep 2015	Estimated future electricity supplied[133]	Total	Estimated cost of waste management (EUR per MWh)
BE[134]	9,2	84%	1 399	349	1 748	5,3
BG	0,9	65%	518	288	807	1,1
CZ	4,6	82%	515	819	1 334	3,4
DE	11,6 Note A	88%	4 836	398	5 234	2,2
ES[135]	10,2	85%	1 829	619	2 448	3,3
FI	5,6	91%	697	344	1 041	5,4
FR[136]	46,9	73%	11 873	9 203	21 076	2,2
HR	0,6	84%	78	60	138	4,4
HU	4,3	86%	389	234	624	6,9

[128] See note 126.

[129] Figure obtained from the Nuclear Decommissioning Authority Annual Report and EDF Energy Financial Statements. It corresponds to the decommissioning of the MAGNOX plants (EUR 19,1 billion) and the plants operated by EDF Energy (EUR 15,9 billion). FX rate used: 1 EUR = 0,7234 GBP.

[130] See note 33.

[131] Sources: National reports submitted by Member States under Council Directive 2011/70/Euratom unless specified otherwise.

[132] Only reactors in operation are considered in the calculation of the average load factor.

[133] Considering LTO projections presented in section 4.3.

[134] See note 123.

[135] Source: see note 112.

[136] Souce: Decommissioning Funding Group and update of the Cigéo project. Note: only costs related to the fleet operated by EDF, including a share of 78% of the estimated costs of Cigéo.

MS	Estimated Waste Management costs (EUR billion)	Lifetime electricity supplied from NPPs [TWh]				Estimated cost of waste management (EUR per MWh)
		Average lifetime load factor[132]	Actual electricity supplied as of Sep 2015	Estimated future electricity supplied[133]	Total	
IT	2,5	48%	143	0	143	17,5
LT	3,2	59%	311	0	311	10,3
NL	Not available	84%	148	54	202	NA
RO	2,8	92%	133	315	448	6,3
SE	7,8	75%	2 200	1 186	3 386	2,3
SI	0,6	84%	78	60	138	4,4
SK	5,0	81%	412	295	707	7,1
UK	24,1	70%	2 629	817	3 445	7,0
Totals	**139,9**	**77%**	**28 187**	**15 719**	**43 905**	**3,2**

Note A: Share of the NPP operators in the investments foreseen for waste disposal facilities, including the Konrad site..

5.3.2 Availability and sufficiency of funds

Member States adopted different models for building up the required funds, with the following basic types:[137]

- The segregated internal fund, kept by the operator of the installation but as a separate budget which can only be used for decommissioning and waste management purposes and under the control of the national body. Funds of this type exist for example in France and Belgium.
- The segregated external fund, meaning external to the operator of the installation, exists in Finland and Sweden, where it is also external from the state budget, and Hungary, Romania, Slovakia and Bulgaria, where the funds are somehow within the State budget.
- Non-segregated internal funds exist in Germany, where the Commercial Law requires the companies operating NPPs to build up reserves in their balance sheets for the future decommissioning and waste management costs.

In most Member States, a single financing regime is intended to cover both waste management and decommissioning activities since they are highly correlated, whereas a few have set up separate funds. An overview of the existing funds and the type of assets where they are invested is presented in Figure 30.

An indicative comparison between the available funds and the total estimated needs is presented in Figure 29. As of 2014, European nuclear operators had dedicated assets that would cover 51 % of the total estimated decommissioning and waste management costs. This compares to the useful life incurred at the same date, estimated at 64 %.

It is important to note that the calculation of the total estimated needs is based on future costs only, whereas the electricity lifetime supply combines past and future production. This is a conservative approach in assessing the adequacy of the existing funds, especially for those Member States where significant investments have already been made. Nevertheless, in general it is assumed that the bulk of the back-end expenses will occur in the future, e.g. with the construction of centralized storage facilities or geological repositories. The calculation is further on the conservative side because it does not consider potential financial incomes obtained on the accumulated funds. Finally, the total electricity supplied depends of course on the date when each plant will be shut-down, which is subject to the uncertainties described in note 47.

Figure 29 Comparison of available funds to accomplished useful life

MS	Funding (EUR billion)	Lifetime electricity supplied from NPPs [TWh]

[137] Source: see note 121.

	Funds available (dedicated assets)	Total estimated needs	%	Actual electricity supplied as of Sep 2015	Estimated future electricity supplied	Total estimated lifetime electricity supplied	%
BE	7,6	13,8	55%	1 399	349	1 748	80%
BG	0,5	3,2	15%	518	288	807	64%
CZ	1,2	6,1	20%	515	819	1 334	39%
DE	38,0 Note A	45,7	83%	4 836	398	5 234	92%
ES	4,3	14,7	29%	1 829	1 297	3 126	59%
FI	2,4	6,6	36%	697	344	1 041	67%
FR	23,0	69,5	33%	11 873	9 203	21 076	56%
HR	0,2	0,8	23%	78	60	138	57%
HU	0,8	5,5	14%	389	234	624	62%
IT	NA	6,4	NA	143	0	143	100%
LT	0,5	4,6	8%	311	0	311	100%
NL	0,1	0,5	29%	148	54	202	73%
RO	0,2	4,2	4%	133	315	448	30%
SE	6,2	11,2	56%	2 200	1 186	3 386	65%
SI	0,2	0,8	24%	78	60	138	57%
SK	1,5	8,1	18%	412	295	707	58%
UK	46,3	61,0	76% Note B	2 629	817	3 445	76%
Totals	**132,9**	**262,5**	**51%**	**28 187**	**15 718**	**43 905**	**64%**

Note A: The regulation in Germany does not require the constitution of specific dedicated assets, but rather refers to the commercial and tax laws to ensure that operators have "sufficient reserves as liabilities on the balance sheet" (Section 249 of the Commercial Code). Accounting provisions are backed up by physical assets, which may experience variations in value in the long term and the German government recently commissioned an independent review which concluded that nuclear operators had sufficient funding to cover the costs of decommissioning and waste management activities. Based on this assessment and provided that the on-going discussions around a possible externalization of the fund management are concluded, we have assumed in our calculation that the available funds are equal to the back-end accounting provisions registered by the nuclear operators as of December 2014.

Note B: We have considered that the related NDA obligations are fully backed by existing funds, since these will be paid from the UK National Budget (Magnox provision of EUR 20,8 billion and geological disposal facility provision of EUR 13,1 billion). The total figure of funds further includes the balance of the Nuclear Liability Fund (EUR 12,4 billion) that is intended to cover the back-end activities linked to the fleet managed by EDF Energy.

Figure 30 Overview of Decommissioning and Waste management funds[138]

MS	Method of Collection	Fund Management			Total funds available (EUR billion)	Investment portfolio
		Internal		External		
		Non-segregated	Segregated			
BE	100% of the estimation's present value		X		7,6	Loans to the operator and third companies: 80%; SICAV: 11% Belgian Sovereign bonds: 2%; Dedicated assets: 5% Corporate bonds and others: 2%
BG	Annual fee based on income from NPPs			X	0,5	State treasury account
CZ	100% of the estimation's present value (Decommissioning) Annual fee based on electricity produced from NPPs (Waste management)	X (Decomm.)		X (Waste Mgt.)	1,2	EUR 0,7 billion in the nuclear account. May be invested on financial markets in liquid state bonds, the Czech National Bank and securities of emitters selected by the Ministry of Finance. EUR 0,5 billion are undisclosed restricted funds in the balance of CEZ.
DE	100% of the estimation's present value	X			38,0	There are no specific requirements. Funds are assumed to equal the accounting provisions.
ES	Annual fee based on electricity produced from NPPs			X	4,3	Debt instruments issued by European Member States.
FI	Annual fee based on waste produced			X	2,4	EUR 1,8 billion were lent back to the operators at Euribor plus 0.5 EUR 0,6 billion were invested in debt issued by the State or other public bodies in Finland and in guaranteed investment instruments.
FR	100% of the estimation's present value		X		23,0	The assets were mainly composed by investments in Equities (33%), Debt instruments (28%), participation in RTE (French Network operator – 11%) and receivables from the French government (CSPE - 22%).
HR	Annual fee - fixed amount of EUR 14.5 million per year			X	0,2	

[138] Sources: 2013 and 2014 Financial Statements of applicable nuclear operators and sources detailed in note 122..

MS	Method of Collection	Fund Management			Total funds available (EUR billion)	Investment portfolio
		Internal		External		
		Non-segregated	Segregated			
HU	Annual fee based on electricity produced from NPPs			X	0,8	State treasury account
IT	Annual fee based on electricity produced			NA	NA	There is no specific fund. The State-owned entity that performs the activities (Sogin) submits its budget for approval to the National Parliament in an annual basis.
LT	State budget and International assistance program			NA	0,5	There is no specific fund. Activities are funded through contributions of the European Union and of the National Government.
NL	Provision following operator's schedule	X		NA	NA	A foundation with separate legal form (i.e. protected from bankruptcy of the operator) has been created to own the funds set aside. No information available of the investment policy.
RO	Annual payments by operator with fixed rate per MWh			X	0,2	State treasury account
SE	Annual fee based on electricity produced			X	6,2	54% covered bonds, 16% Treasury Bonds, 26% Index-linked bonds and 4% cash
SI	Annual fee based on electricity produced			X	0,2	53% Government bonds, 15% corporate bonds, 24% mutual funds, 8% equities.
SK	Annual fee based on electricity produced and fixed % from total sales of electricity			X	1,5	State treasury account
UK	Fixed fee + variable fee based on tonne of uranium loaded into Sizewell B reactor			X	46,3	EUR 12,4 billion at the Nuclear Liability Fund was invested in National Loans Fund (86% of the balance, providing 0.4% annual return) and other investments such as UK, North America or European equities. NDA activities are financed every year from the current budget. For the calculation, an availability rate of 100% has been applied.

5.3.3 Accounting provisions

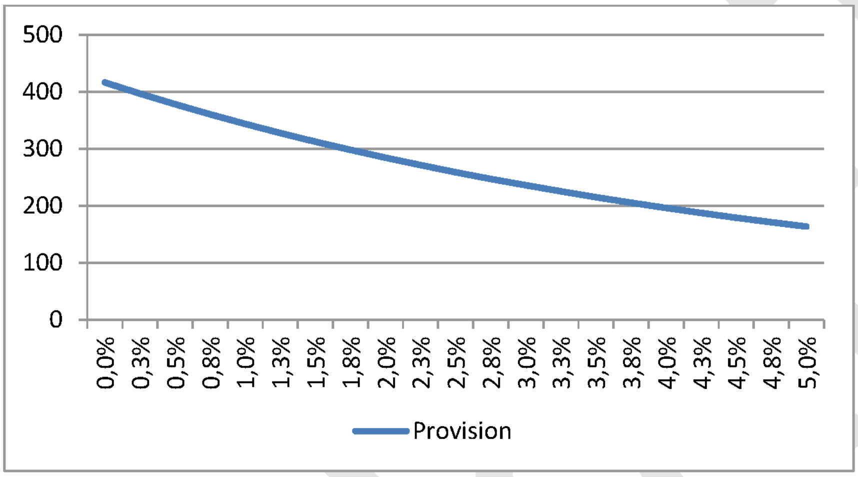
Accounting provisions and funds available are different concepts. Provisions are backed up by physical assets from the balance sheet with different degrees of liquidity and which may experience variations in value in the long term. They are defined by the international accounting standards. On the other hand, funds available are normally backed by dedicated assets with typically higher liquidity, follow a conservative investment strategy and are protected in case of bankruptcy. They are determined by the national regulator.

The analysis performed so far was focused in the funds available. Accounting provisions are important because they influence the credit rating of the nuclear operators. These provisions are based on the same cost estimations that determine the required funding and in a discount rate that is applied to calculate the costs over time (i.e. translate a future capital investment into an equivalent present value).

Nuclear back-end provisions are calculated as $\sum_{i=0}^{n} \frac{Cost_i}{(1+d)^i}$.

The higher the discount rate, the lower the present value of the provisions is.

Figure 31 Illustrative impact of the discount rate in nuclear provisions[139]



European nuclear operators have constituted provisions in their balance sheets related to future costs expected from the decommissioning of nuclear power plants and the management and disposal of radioactive waste. Small variations in the discount rates applied would have a significant effect in these provisions. Discount rates differ among Member States and even among companies operating in the same Member State.

Figure 32 Discount rates used in back-end provisions[140]

BE	BG	CZ	DE (note A)	ES	FI	FR	HR	HU	IT	LT	NL (note A)	RO	SE (note A)	SI	SK	UK (note A)
2,8%	2,0%	1,8%	2,0% to 2,8%	1,5%	3,5%	2,9%	(note C)	3,0%	(note B)	(note B)	2,5%	(note C)	2,0% to 3,0%	(note C)	1,7%	2,2% to 3,0%

Note A: Discount rates were reported in nominal terms. A 2% long-term inflation rate has been used to obtain the real discount rate for comparison purposes
Note B: Italy does not have dedicated decommissioning and waste management funds. Lithuania's decommissioning project receives funding assistance from the EU
Note C: Data not available

[139] Calculation for a generic cost of decommissioning one reactor of EUR 417 million with decommissioning activities to be started in 2028 and to last 7 years.

[140] Sources: see note 122.

The discount rate should reflect the current market assessment of the time value of money and the risks specific to the liability [IAS 37.45 and 37.47]. Some Member States, such as France, have decided to provide more clarity by imposing conditions so that the rate is:

a) Below a cap calculated in line with variable market conditions;
b) Lower than the expected rate of return on assets covering the liability (dedicated assets), and
c) Consistent in time.

6 Cost summary

Figure 33 Summary of the estimated projections

Concept	(EUR billion)
Nuclear new build	349 to 455
Long term operations	47
Decommissioning	123
Waste management,	140
from which Final disposal facility	74
Total	**659 to 765**

Comparison to the results of the World Energy Outlook

a) Investments in nuclear power capacity

The 2015 World Energy Outlook (WEO 2015) provides data on energy projections until 2040, for a set of three different scenarios:

1. The **Current Policies Scenario** takes into consideration only those policies for which implementing measures had been formally adopted as of mid-2015 and makes the assumption that these policies persist unchanged.
2. The **New Policies Scenario** also takes account of other relevant intentions that have been announced, even when the precise implementing measures have yet to be fully defined.
3. The **450 Scenario** assumes a set of policies that bring about a trajectory of greenhouse-gas (GHG) emissions from the energy sector that is consistent with the international goal to limit the rise in the long-term average global temperature to two degrees Celsius (2 °C), compared with pre-industrial levels.

The projections of nuclear capacity and related electricity production presented in the PINC fall within the range between the Current Policies and the New Policies scenarios, as can be seen in Figure 34. In terms of investment, the WEO 2015 is below the lower end of the estimations from the PINC. This means that even though the final picture is similar, the cost assumptions used in the PINC are above those at the WEO.

When considering the 450 Scenario, it can be seen that projections of nuclear power capacity from the PINC are very conservative, suggesting that nuclear energy will have to play a more important role to achieve an objective of limiting the rise in the long-term average global temperature to 2 °C.

Figure 34 Comparison of cumulative investments in nuclear power capacity in Europe[141]

	PINC projection	New Policies Scenario	Current Policies Scenario	450 Scenario
Investment in nuclear capacity 2015-2040 (billion EUR)	241 – 309 Note A	222	Not disclosed	

[141] Source: International Energy Agency, World Energy Outlook. (2015).

Nuclear capacity by 2040 (GWe)	105	110	92	126
Nuclear contribution to the gross electricity production by 2040	19%	23%	17%	27%

Note A: The WEO presents the combined investment in new build and in LTO of the current fleet. Therefore, the PINC figures are obtained by adding the results presented in sections 3.3 and 4.3.

b) Investments in decommissioning and waste management

The WEO 2015 does not report estimations on nuclear plants decommissioning and waste management activities. However, the 2014 version included a specific outlook on nuclear power where the decommissioning costs to 2040 were estimated in EUR 38 billion[142] (compared to the PINC figure of EUR 123 billion). There is a significant difference, even though the scope of the projection is to 2040 in the former and to 2050 in the later (with a significant number of NPPs being decommissioned in the last decade of the projection). Nevertheless, some of the reactions to the WEO2014 point towards a potential understatement of the decommissioning cost estimation.[143]

The WEO2014 did not disclose the estimation of investments needed in waste management activities.

Finally and for the sake of completeness, it's worth noting that the WEO 2015 estimates the total investments in Power Generation in Europe until 2040 to be EUR 1 287 billion (consequently, investments in nuclear generation would represent 17% of the total), and the investments in Transmission and Distribution EUR 574 billion.

Comparison to the results of the EU Reference Scenario 2016

The EU Reference Scenario focuses on the EU energy system, transport and GHG emission developments, including specific sections on emission trends not related to energy, and on the various interactions among policies in these sectors. Its time horizon is up to 2050 and it includes all EU28 Member States individually.

The objective of this periodic exercise is to provide a reference that acts as a benchmark of current policy and market trends. As such, it can help to inform future policy debate and policy making, pointing for example at areas where the current policy framework falls short of reaching the EU's climate and energy objectives. Notably, the 2016 EU Reference Scenario[144] shows that current policy and market conditions will deliver neither the 2030 targets nor the long-term 2050 80-95 % GHG emission reduction objective.

The projections of the EU Reference Scenario 2016 regarding nuclear power are in line with the low-range projections presented in section 3 of this document. However, even when the picture projected in 2050 is similar, the path to reach there slightly differs between both exercises:

- Nuclear installed capacity in 2050 is projected to be 93 GW (vs 95 GW in the low range of the PINC), representing 17,8 % of the electricity mix (in line with the PINC).
- The EU Reference Scenario projects that investments will be needed to provide for the following capacities in nuclear power until 2050:
  - New build: 72 GW (vs 81 GW in the PINC);
  - Extensions in the lifetime of existing plants (LTO): 87 GW (vs 72 GW in the PINC).

The reason for this difference is mainly explained by the fact that the EU Reference Scenario only takes into consideration the agreed policies at EU and Member State levels until December 2014, particularly leaving outside the scope the French "Energy Transition for Green Growth Act" adopted on July 2015 and which is considered in the PINC.

Nuclear research priorities

[142] Source: see note 11.

[143] e.g. indication from the IEA's head of power generation analysis at http://uk.reuters.com/article/2015/01/19/us-nuclear-decommissioning-idUSKBN0KS0R920150119

[144] https://ec.europa.eu/energy/sites/ener/files/documents/ref2016_report_final-web.pdf

The European Commission appreciates the benefits from the increasing interaction between European Technology Platforms (ETPs), namely the 'Sustainable Nuclear Energy Technology Platform' (SNETP) incorporating NUGENIA (Association on research and development of nuclear fission technologies, with a focus on Generation II and III nuclear plants), ESNII Generation IV fast reactors, employing the closed fuel cycle, and NC2I Cogeneration of electricity and heat, the 'Implementing Geological Disposal of Radioactive Waste Technology Platform' (IGDTP), the 'Multidisciplinary European Low Dose Initiative' (MELODI association), the European Energy Research Alliance (EERA) Joint Programme in Nuclear Materials (JPNM) and other EU stakeholder forums (ENEF, ENSREG, WENRA, ETSON, FORATOM, etc.) as well as OECD/NEA, GIF and IAEA at international level.

Nuclear research and innovation have an important international dimension. Nuclear challenges, being of global nature (in particular nuclear safety), require common responses at an international level. Science diplomacy and further global scientific collaboration with third countries in nuclear research is encouraged.

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