EN13 Nuclear Waste Production

Key message

The amount of highly radioactive waste from nuclear power production continues to accumulate and a generally acceptable disposal route for this waste has yet to be identified. The related potential health and environmental risks, as well as issues surrounding nuclear proliferation, therefore continue to be a cause for concern. However, new technological developments allow for safer reactor designs and higher efficiencies, and lower production of waste. Furthermore, nuclear energy could play a role in meeting growing concerns over security of supply and CO_2-emission reductions.

Rationale

Nuclear power is responsible for a steady accumulation of radioactive waste that poses a potential threat to the environment and human health. The quantity of spent nuclear fuel produced provides a reliable representation of the accumulation of radioactive waste and its evolution over time. On the other hand, nuclear power can contribute to combat global warming and to security of supply.

1. Indicator Assessment

This indicator focuses on the production of nuclear waste: production, reprocessing and storage. In addition attention is paid to aspects related to nuclear power production, including: safety, proliferation, new technology and developments regarding existing and new nuclear plants.

Nuclear power production in the EU:

Within the EU27 a division can be made between countries in which a large fraction (> 20%) of power production is based on nuclear energy and countries in which nuclear power production is absent or contributes very little to total power production. Overall the production of nuclear power has increased by over 20% from 1990 to present. This is mainly due to increased plant availability and increases in net plant efficiencies. The share of nuclear power production in total electricity production slightly declined from approximately 32% in 1990 to 30% in 2005 (see indicator EN27).

Anticipated developments in nuclear power production include (Source: World Nuclear Association: http://www.world-nuclear.org/info/inf17.html)):

For existing capacity:

- Several countries, like the Netherlands, Belgium and Hungary have decided to extend the life-time of existing NPPs.
- Spain has a program to add 810 MWe (11%) to its nuclear capacity through upgrading its nine reactors by up to 13%. For instance, the Almarez nuclear plant is being boosted by more than 5% at a cost of US$ 50 million. Some 519 MWe of the increase is already in place.
- Finland has boosted the capacity of the Olkiluoto plant by 29% to 1700 MWe. This plant started with two 660 MWe Swedish BWRs commissioned in 1978 and 1980. It is now licensed to operate to 2018. The Loviisa plant, with two VVER-440 (PWR) reactors, has been upgraded by 90 MWe (10%).
- Sweden is upgrading Forsmark plant by 13% (410 MWe) over 2008-10 at a cost of EUR 225 million, and Oskarshamn-3 by 21% to 1450 MWe at a cost of EUR 180 million.

New power plants:

- In Finland (Olikiluoto) and France (Flamanville), the process of building additional capacity, based on new nuclear designs such as the European Pressurised Water Reactor (EPR), is ongoing. Both are planned to start-up in 2012.

- In Romania, the new Cernavoda 2 reactor was finished first power in October 2007. Two further units are expected to commence construction soon.

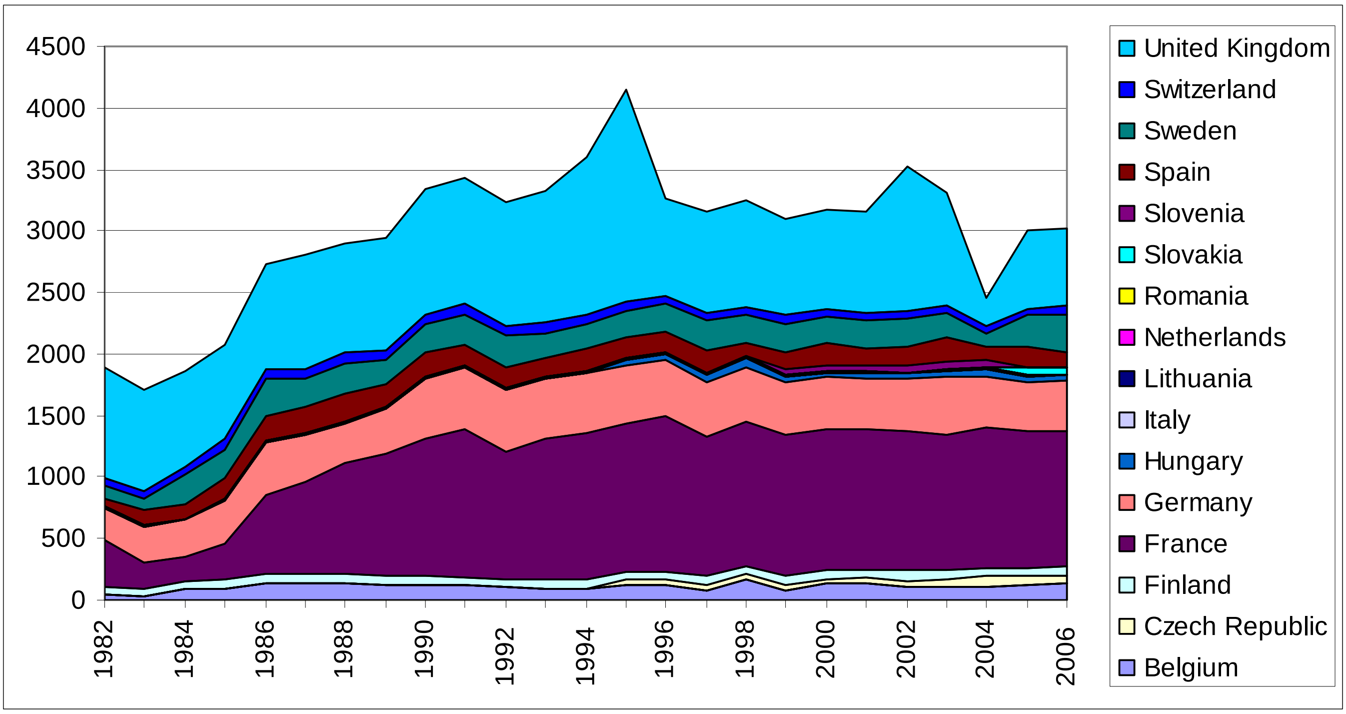
- Bulgaria is about to start building two 1000 MWe Russian reactors at Belene.

- The three Baltic states agreed in 2006 on the construction of a NPP in Luthuania by 2015. Possibly, Poland will join this project.

Wastes:

The historical series of spent fuel arising is given in Fig. 1. The information presented refers to the quantity of heavy metals in nuclear fuel, which make up approximately 85% of the uranium fuel and 60% - 70% of the aggregation of fuel and fuel casing (fuel assembly).

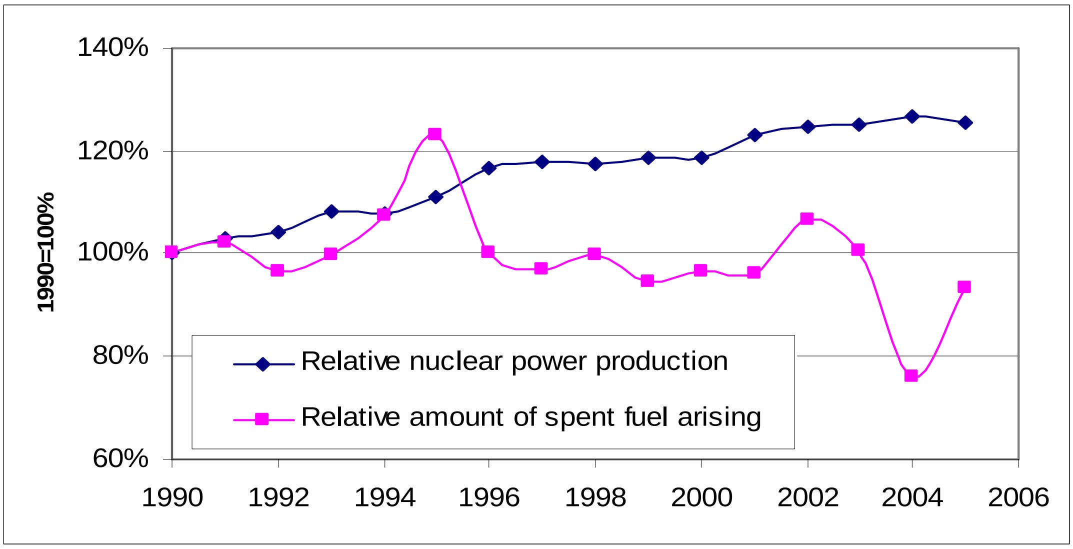
Fig. 1: Historic series in spent fuel arising (tonnes heavy metals).



Data source: (OECD, 2007), (IAEA, 2003b), (NEA, 2007)
Notes: No information has been included for Bulgaria due to a lack of data.

Arising amounts of spent fuel depend primarily on the amount of power produced, but also to a large extent on the type of reactor, level of fuel enrichment, fuel burnup and net power plant electric efficiency. Arising amounts of spent fuel show a limited decline (approximately 5%) for the period 1990 - 2006, while produced power increased in this period by over 20% (see EN27 for more details). Since very few new nuclear power plants have come online since 1990 and several plants in UK, Lithuania, Germany, Sweden and Bulgaria have been shut down (WNA website) these trends illustrate increased plant availability in the past decades and increases in net plant electric efficiency of approximately 10 percentage points to approximately 32% (WORLD, 2003). They also illustrate the trend in increasing fuel enrichment and fuel burnup and the resulting reduction in spent fuel arising per unit of power. This trend is likely to continue in the future.

Fig 2. EU Electricity production from nuclear power (percentages relative to 1990 level)



Data source: (OECD, 2007), (IAEA, 2003b), (NEA, 2007), Eurostat

Plant closures tend to result in a peak in spent fuel arising as after closure all the fuel present in the reactor core is removed. By, contrast during power production around ¼ to 1/3 is removed annually as spent fuel. The effects of plant closure on spent fuel production are most pronounced for the UK with decommissioning at Berkley (1989), Trawsfynydd (1993), Hinkley Point (2000) and Bradwell (2002) resulting in the peaks in the graph.

Future development of annually arising spent fuel quantities depends primarily on: political developments and related developments of nuclear power production capacity (new capacity constructed, the type of the new capacity – III and III+ generation or new capacity from upgrading or extending the economic life of existing plants or existing capacity decommissioned),and national policies concerning reprocessing in countries other than France and UK.

Reprocessing:

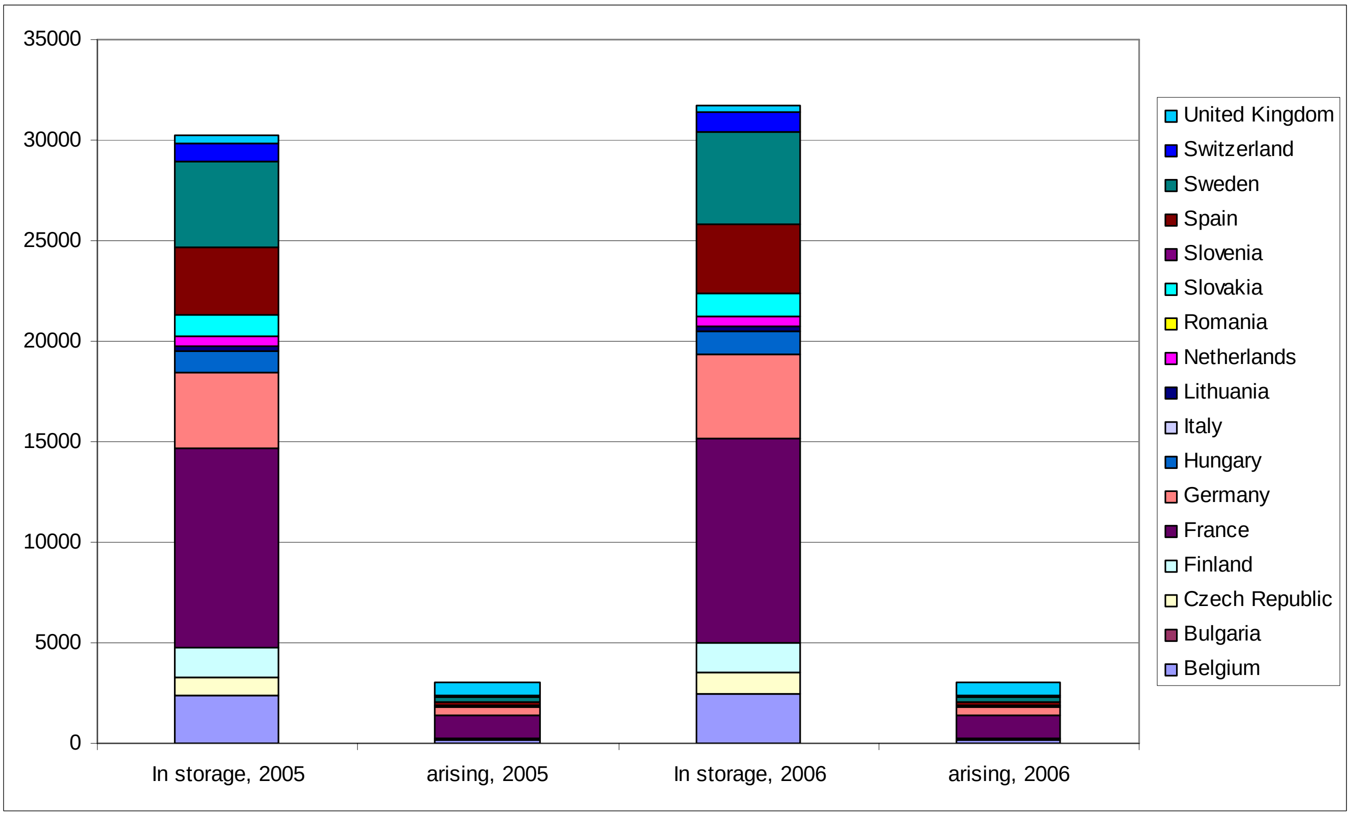
The arising amount of spent fuel is not equivalent to the amount of high level waste to be stored, since part of this spent fuel is reprocessed. During reprocessing uranium and the plutonium generated in the reactor are separated from (other) fission products and fuel rod casing for reuse. Uranium is re-enriched (RepU) and reused as nuclear fuel, whilst plutonium is mixed with depleted uranium or tails to create MOX (mixed oxides, ie. nuclear fuel containing both U and Pu oxides), which is also intended as a nuclear fuel. Fission products and fuel rod casings are melted into borosilicate glass and are destined for temporary storage and final disposal. Reprocessing separated uranium is less attractive than using fresh uranium because of the presence of neutron absorbing and gamma radiation emitting uranium isotopes (see e.g. Harvard, 2003 and MIT, 2003). Total reprocessing capacity in France and the UK amounts to 4.100 tonnes of heavy metals per year, and will reduce to 2.600 tonnes due to the closure of Sellafield B 205. In the past decades approximately 72.600 tonnes of heavy metals have been reprocessed (WNA website).

Storage:

Stored amounts of spent fuel and reprocessing wastes are given in Fig. 3. Storage capacity has not been included because it is relatively easy to create extra (temporary) storage capacity (e.g. spent fuel rack rearranging or canister storage). Available storage capacity therefore has little informative value.

Spent nuclear fuel is the most highly radioactive waste. It decays rapidly at first, i.e. after 40 years the level of radioactivity has typically dropped to 1/1000th of the initial value. But it takes around 1000 years to drop to the level of the original uranium ore which was needed to produce that quantity of spent fuel (WNA, 2003). The potential impact of nuclear waste on humans and the environment depends on the level of radioactivity and on the conditions under which the waste is managed. The majority of Member States currently store spent fuel and other high level radioactive wastes in above ground storage facilities and a generally acceptable disposal route for this waste has yet to be identified. However, deep geological disposal in an underground repository is currently favoured as a long-term option by many countries. Geological disposal facilities currently operate in Finland and Sweden. Lower level radioactive wastes are commonly stored in surface disposal sites.

Fig. 3 Total stored amount of high level waste (in tonnes of heavy metals)



Data source: (IAEA, 2003b), (NEA, 2007)
Notes: No information has been included for Bulgaria due to a lack of data.

Spent fuel is first stored for several years (usually < 10, but sometimes > 20) in spent fuel ponds 'at reactor' (AR) to allow the reduction of radioactive activity of the fuel to a level at which heat generation and radiation are low enough to allow for handling. After this period fuel is either reprocessed or temporarily stored. Temporary storage, for a period of 50 – 100 years is required, for a further decrease of radioactive activity and heat generation before final storage is possible. Spent fuel in the EU is temporarily stored in both wet and dry storage systems. Facilities are designed to limit radiation to surroundings and to remove the heat from the spent fuel. Storage capacity in Western and Eastern Europe 'away from reactor' (AFR) is approximately 66 ktonnes of heavy metals (HM), of which approximately 53 ktonnes HM is wet storage (IAEA, 2003a).
Interim storage facilities range from bunkers able to withstand airplane crashes (such as Habog in the Netherlands) to open air storage in canisters. There is presently no commercial storage facility for permanent storage of HLW (HLW = High level waste). Facilities are being designed and are planned to become operational in 2020 – 2025 in Belgium, Czech Republic, Finland, Netherlands, Spain, Sweden and France.

The risk of insufficiently safe storage of radioactive waste is illustrated by the tritium leakages at the full and closed Centre Stockage de la Manche and Centre de Stockage de l'Aube (both in France) to the surrounding groundwater (http://www.acro.eu.org/ and Burnie, 2007).

Costs:

The costs of nuclear power production are a subject of intense discussion and estimates range from very low costs of e.g. 2 €ct/kWh$_e$ to more than 10 €ct/kWh$_e$ (ECN, 2007). Production cost estimates for the intended EPR (European Pressurised Reactor) power plants in France amount to €ct 4.6/kWh (ECN, 2007). Differences between estimated production costs are mainly due to differences in the applied depreciation methodology, depreciation period and interest rates. Costs for insurance may make up 30% of total operational costs. Decommissioning costs are covered by a fund created from sales during the operational lifetime of the plant, in other words are accounted for in the project cash-flow.

Safety:

Risks are determined by a probabilistic safety assessment (PSA). PSA is conducted at three levels:

- Core melt (PSA 1);
- Release of radioactive materials and radiation from a core melt or other events to the surroundings (PSA 2);
- Occurrence of damage in the surroundings (PSA 3).

Accidents and resulting releases of radioactive material and radioactive radiation are categorized according to the INES scale International Nuclear Event Scale), with INES 7 referring to a major accident. The vast majority of reported events are found to be below Level 3. The Chernobyl accident is regarded in the nuclear power industry as a non-representative exception and is rated as an INES 7 event. Next to this accident one other INES 5 event and three INES 4 events have occurred since nuclear power production became commercially available. The INES 5 event, the Three Mile Island accident, is viewed in the nuclear industry as the evidence that a well designed power plant with a containment structure can absorb even a partial core melt without an impact on the surroundings.

The distribution of nuclear power technology to unstable nations and reprocessing are the main focus of the discussion concerning non-proliferation. Reprocessing is viewed as a sensitive step in the nuclear fuel cycle because of the isolation of plutonium. The isolated plutonium could be used for construction of a primitive nuclear weapon. However, this requires significant technological knowhow and becomes more difficult with higher fuel burnup because the concentration of fissile Pu-239 in the plutonium isolated in reprocessing reduces with higher burnup, while the concentration of poorly fissile and fission hindering Pu-240 increases. The current trend in fuel utilisation is increased burnup, reducing the applicability of the isolated plutonium.

New technology (e.g. 3rd/4th generation):

Technological development in the recent decade has resulted in improved versions of existing LWR reactor designs, such as the EPR, AP-1000, ESBWR and ABWR: the so-called generation III or III^{+} designs. These have a somewhat higher net electric efficiency compared to current updated generation II reactors (35% - 39% compared to 33% - 35%, (TUD, 2006)) and allow for higher fuel burnup, higher fuel assay and a higher percentage of MOX in the fuel. These specifications mean less fuel is required per kWh_e and a larger percentage of spent fuel can be reprocessed. They are also intrinsically safer than updated generation II reactors because of automatic safety features built in to avoid human errors.

Development of new reactor designs is coordinated in the so-called Generation IV International Forum (GIF). This is a US-led grouping set up in 2001 and joined by the EU in 2005 which has identified six reactor concepts for further investigation with a view to commercial deployment by 2030. A number of these reactor designs are intrinsically safe. Higher operational temperature will result in higher energy efficiency. Parallel to the Generation IV forum the Pebble Bed Modular Reactor (PBMR) is being developed in South Africa and China. Net efficiency will be 42%, burnup will be at least 90 GWday/tU but may be increased eventually to 200 GWday/tU. At a burnup of 90 GWday/tU the amount of spent fuel per unit of delivered electricity will be 60% smaller than for current Generation II reactors.

2. Indicator rationale

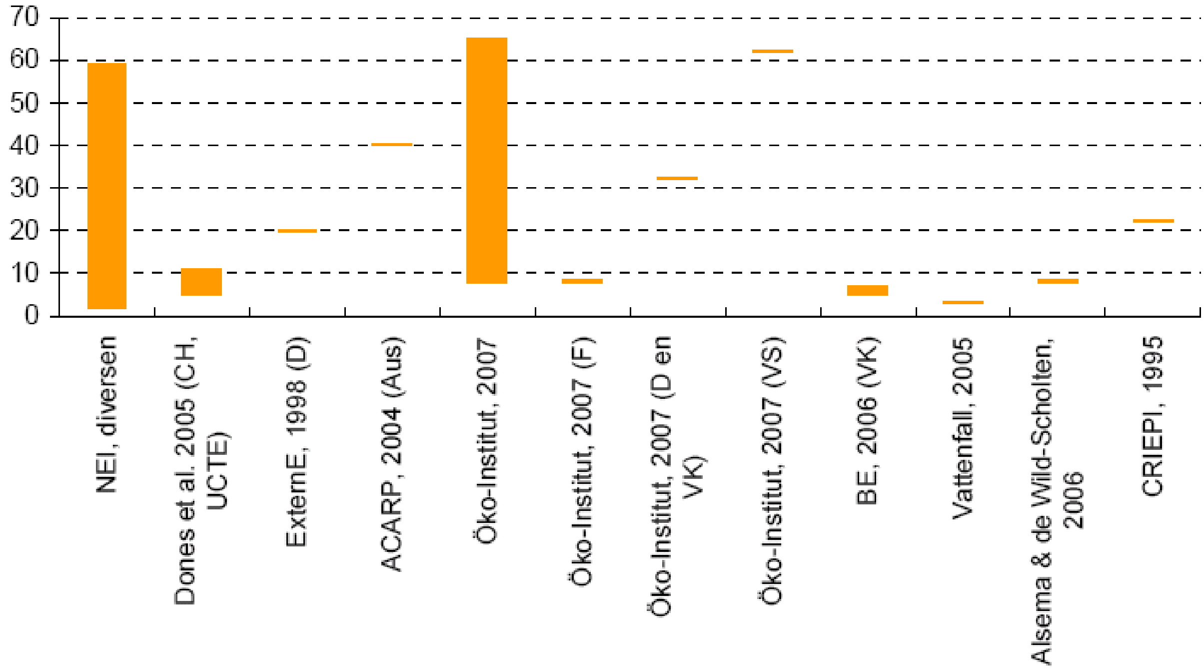
2.1 Environmental context

Nuclear waste production is a pressure indicator. The annual and accumulated amount and level of activity of nuclear waste and its development give a broad indication of associated potential environmental and health risks. Storage and final disposal of spent fuel and other nuclear waste poses a potential risk of quantities of radiation being released to the environment (to the atmosphere and/or land and/or water). The release of radioactivity to the environment can result in acute or chronic impacts that, in extreme cases, can cause loss of biota in the short term and genetic mutation in the longer term, both of which may result in unknown and potentially fatal effects. Increased levels of radioactivity can also be passed up through the food chain and affect human food resources.

Nuclear power, unlike fossil fuel, does not generate GHG directly. For nuclear power and renewable fuels, there are no GHG emissions at the point of generation, but there are releases during the mining and processing of the fuel, construction of the plant, disposal of spent fuel and by-products, and waste management and decommissioning. The emissions from these stages depend, among other factors, on the national mix of electric power production. For example, the GHG emissions from a nuclear fuel cycle are due to the fossil fuel-based energy and electricity needed to mine and process fuel and for the construction and materials of fuel cycle facilities. However, it is recognized that nuclear power produces low emissions of carbon dioxide and lower emissions of acidic gases compared to fossil fuel-based electricity generation (taking into account the entire life-cycle). In the European Strategic Energy Plan nuclear power has been considered a key low-carbon technology (COM(2006) 847 final) and in the presidency conclusions of the European Council of 8/9 march (European Council,2007) it was noted that nuclear energy could make a contribution to achieving CO_2-reductions.

An overview of net GHG-emissions per kWhe calculated in different LCA (Life Cycle Analysis) studies is given in Figure 4. For comparison, specific emissions for a modern coal fired power plant or natural gas fired combined cycle power plant would amount to 720 g/kWh$_e$ and 340 g/kWh ,respectively.

Fig. 4 Net specific GHG emission (in g/kWh$_e$) of nuclear power, from a sample of different LCA studies



Data source: ECN (2007)

2.2 Policy-context

Decisions concerning the use of nuclear energy are up to Member States as the principle of subsidiarity grants member states autonomy in deciding their energy mix.

Policy developments in Member States

In the past few years, public concern about environmental and safety considerations have led to plans to phase out nuclear power in certain Member States (such as Germany, the Netherlands, Spain, Sweden and Belgium), with some others either declaring or considering moratoria on the building of new nuclear plants. Italy completely phased-out nuclear power following a referendum in 1987. In Sweden the Barseback nuclear power plant closed in 2005. In Germany several NPP's are planned to be closed by 2009. In Slovakia, the completion of two reactors has been put on hold and Poland halted the construction of its nuclear power plant.

Recently, within several Member States a shift towards the use of nuclear energy appears to have been made as nuclear energy could play a role in combating climate change and securing energy supplies. For instance, in January 2008, the UK government announced the decision to build new nuclear capacity. This was followed by statements from Turkey, which is planning to build 5 new NPP's and a reprocessing unit.

EU policies and regulations
The European Commission (COM 2007[2]) and the presidency conclusions of the European Council of 8/9 March 2007 (European Council, 2007) noted that nuclear energy could make a contribution to meeting growing concerns about the security of energy supply and CO_2 emission reductions. The council suggests a broad discussion among all stakeholders on the opportunities and risks of nuclear energy. Nuclear power has been considered by the EC as part of key low-carbon technologies ('technology avenue') as identified in the European Strategic Energy Plan (see COM(2007) and COM(2006) 847 final).

The European Commission's work and strategy for radioactive waste management and decommissioning of nuclear facilities is further set out in the following documents oriented towards safety and environmental protection concerns, with particular regard for the safe management of long-lived radioactive waste or final disposal of radioactive waste. These include the Community Plan of Action in the field of Radioactive Waste, renewed for the period 1993–99 by a Council Resolution in June 1992 (92/C158/02), and COM (2002) 605 final, on nuclear safety in the European Union, which proposes that Member States commit themselves to authorise deep disposal sites for highly radioactive waste by 2008 and to bring such sites into operation by 2018. Furthermore, the European Commission suggested more support for research and development on nuclear waste management in its proposal for a sustainable development strategy (EC, 2001) and proposed a directive on the management of nuclear waste (EC, 2004c; EC, 2002e).

According to recent communications, The European Commission regards nuclear energy as a key element in future low-carbon energy systems. President Barroso announced at the start of the Sustainable Nuclear Energy Forum (26 November 2007) that "nuclear energy can have a role to play in meeting our growing concerns about security of supply and CO_2-emission reduction". The "Sustainable Nuclear Energy Forum" brings together stakeholders, and aims at facilitating an open public debate and dialogue on sustainable development of nuclear energy. Also, a High Level Group on Nuclear Safety was established. This group of representatives of Member States and the Commission, focuses on sharing expertise in nuclear safety, and proposing possible European rules for safety standards. Furthermore, research regarding the "sustainable" use of nuclear energy is part of the Strategic Energy Technology Plan, that was presented on 22 November (IP/07/1750).

Present EU-regulations include the 1957 EURATOM Treaty which addresses issues in the field of nuclear power such as radiation protection of the work force and the public, the supply of fissile nuclear materials for the development of the nuclear power sector, the safeguarding of nuclear fissile materials to prevent them from being used for unauthorised military purposes, and general aspects such as research and dissemination of information. However, the treaty makes little or no specific mention of aspects such as operational safety of nuclear power plants and radioactive waste storage or disposal facilities.

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Meta data

Technical information

1. Data source:
   Spent fuel (historical and projected data)– OECD Environmental Data: Compendium 2004 http://www.oecd.org, OECD Nuclear Energy Agency 2005 http://www.nea.fr/, and IAEA, 2003
   Production of electricity from nuclear (historical data)- Eurostat http://europa.eu.int/comm/eurostat/

2. Description of data/Indicator definition:
   The indicator measures spent nuclear fuel arising from nuclear electricity production in the Member States that had nuclear powered

electricity production capacity between 1990 and 2006 (data for Bulgaria missing). It provides an indication of the situation of radioactive waste accumulation and storage.
Original measurement units:
Spent fuel: tonnes of heavy metal (tHM)
Nuclear electricity generation: terawatt hours (TWh)
According to the World Energy Council http://www.worldenergy.org/wec-geis/focus/nuclear/ nuclear waste falls into the following four broad categories:
Very low-level waste (VLLW) contains negligible amounts of radioactivity, which can, depending on the clearance level, be disposed of in a dedicated surface site or with domestic refuse.
Low-level waste (LLW) contains small amounts of radioactivity and negligible amounts of long-lived waste.
Intermediate-level waste (ILW) contains higher amounts of radioactivity and does require shielding in the form of lead, concrete or water. It is further categorised into short-lived and long-lived. The former is dealt with in a similar way to LLW and the latter to HLW.
High-level waste (HLW) is highly radioactive, contains long-lived radioactivity and generates a considerable amount of heat.
HLW accounts for 10% by volume of radioactive waste generated and contains about 99% of the total radioactivity. This includes fission products and spent fuel.

3. Geographical coverage:
Data on the annual production of radioactive waste (in tonnes of heavy metal) is available for EU countries that are members of the OECD: Belgium, Czech Republic, Finland, France, Germany, Hungary, the Netherlands, Slovakia, Spain, Sweden and United Kingdom. IAEA, 2003 provides information for Romania, Lithuania and Slovenia

4. Temporal coverage:
1990-2006; projections, 2010, 2015, 2020 and 2030 are available but are not included.

5. Methodology and frequency of data collection:
Data collected annually.

6. Methodology of data manipulation:
Average annual rate of growth calculated using: [(last year / base year) ^ (1 / number of years) –1]*100

Qualitative information

7. Strengths and weaknesses (at data level)
Time series data on spent fuel arisings is limited for the Czech Republic (since 1995), Hungary (since 1995), Slovakia (since 1999). No data is available for Slovenia, Lithuania, Romania and Bulgaria that also have nuclear electricity production.
For the production of electricity, data have traditionally been compiled by Eurostat through the annual Joint Questionnaires (although there is no separate questionnaire for nuclear energy), shared by Eurostat and the International Energy Agency, following a well-established and harmonised methodology. The primary energy from nuclear is calculated based on the electricity generation from nuclear with a 33.3 % efficiency rate. Methodological information on the annual Joint Questionnaires and data compilation can be found on Eurostat's website in the section on metadata on energy statistics. http://europa.eu.int/estatref/info/sdds/en/sirene/energy_base.htm

8. Reliability, accuracy, robustness, uncertainty (at data level):
Data on spent fuel arisings have been compiled by the OECD using data from member Governments. This is a consistent ongoing process that is updated annually. However, annually arising amounts of spent fuel produced in Slovenia, Lithuania and Romania have to be estimated based on IAEA, 2003. No data is available for Bulgaria which decreases the overall accuracy of the indicator.
The use of spent fuel arisings as a proxy for overall radioactive waste is itself slightly uncertain because of the various inconsistencies in classification of radioactive waste between Member States, although it does provide a ‘reliable representation of the production of radioactive waste situation and its evolution over time’ (OECD, 1993).

9. Overall scoring – (1 = no major problems, 3 = major reservations):
Relevance: 1
Accuracy: 2