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The Role of Nuclear Power in Europe

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FOREWORD

Energy in general, and electricity in particular, is essential for economic and social development, prosperity, health and security of citizens: GDP is also closely related to energy consumption/cost/quality of supply.

The world population over the last 10 years has increased by more than 12%, and today, East & South East Asia together with South Asia (E-SE&S Asia) account for more than 55% of the global population; while Europe has seen a 1.4% increase in population and is now home to 13.6% of the 6.4 billion people in the world.

At the same time, the world primary energy consumption, currently around 11,000 Mtoe, has seen an increase of 20% again led by E-SE&S Asia with an increase of around 35% compared to 7.3% in Europe. The world electricity consumption, currently at about 18,000 TWh, has increased by 31.5% with E-SE&S Asia increasing by 60% compared to 16% in Europe. Considering the dramatic increase in demand for electricity driven by E-SE&S Asia (e.g. China and India) and by the fact that around 1.7 billion people in the world today do not have access to electricity, there are widely spread expectations of impending high and volatile fossil fuel prices, compounded by security of supply concerns for the leading primary energy resources and environmental impacts due to the extremely high growth of coal plants in E-S&SE Asia and gas CCGT plants in liberalised markets.

Given these developments, nuclear power is again becoming the subject for analysis and discussions, at political, scientific and technical levels. A potential recourse to nuclear power basically depends on environmental concerns, public acceptance and on nuclear's economic competitiveness compared to other energy sources both renewable and fossil fuels.

Considering:

- Europe's (excluding Russia) heavy dependency on external energy supplies (50% today and more than 70% in 2030)
- the key role of Russia and other CSI countries in the European energy scene
- the necessary investments to meet growth in demand and to replace aging power plants
- the European commitment to CO_2 emissions reduction
- Europe's competitiveness in the global economy

In 2005, the European Regional Group of the World Energy Council (WEC) decided to launch a study to define the conditions nuclear energy should meet, to be re-integrated into the European electricity market.

The Study was included in the WEC Regional Action Plan, as a priority issue.

The study group was created in March 2005 and included 25 members from 17 of the 36 European countries. The group has also benefited from contacts with international organisations such as the IAEA, Foratom and the NEA, to get external points of view on the project. The results of the study group's work are presented in this study.

The first study group meeting was held in Bucharest in May 2005, and the fifth and final meeting in Helsinki in November 2006. The study work was organised around four major topics:

- Electricity in Europe (coordinated by Santiago San Antonio & Antonio Gonzalez Jimenez)
- Overview of existing nuclear power plants (coordinated by Fernando Naredo)
- Developing of new nuclear power plants with existing technologies (coordinated by Didier Beutier and Michel Benard)
- New nuclear power technologies (coordinated by Frank Carré)

Both on behalf of WEC and personally, I would like to thank all study group members for their valuable and much appreciated contributions. Special thanks are due to the chapter coordinators for their efforts in putting together numerous drafts. Thanks also go to IAEA, Foratom and NEA for their contribution to the study and to all companies and organisations that made their staff available for this unique effort.

I would also like to thank WEC Director of Programmes, Elena Nekhaev, for her guidance and support in finalising the study and WEC Regional Coordinator for Europe, Slav Slavov, who has supported and encouraged activities of the study group and organised all meetings.

Finally, it was a new and stimulating experience to work together with all members of the study group who represented a diverse range of experience and backgrounds. The commitment of individual members and the team spirit of the group have greatly facilitated our work.

Dr. Alessandro Clerici
Study Chair

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CHAPTER 1: ELECTRICITY IN EUROPE[1]

1.1 Introduction

Energy will remain one of the major issues of the 21st century, especially in Europe; given its high dependency on energy imports. Energy demand continues to increase, raising concerns about supply, the economic competitiveness of different sources, and repercussions on the economic and social development and the environment. Consequently, consideration should be given to all these factors, to which others of special relevance may be added, such as liberalisation of the energy markets, waste management and public acceptance of different technologies, all of which have a certain impact on the energy scene.

A number of countries around the world, including the United Kingdom (UK) and the United States (US), are showing a growing interest in the potential role of nuclear power in meeting some of the challenges of the next thirty years - the growing demand for energy and particularly for electricity, the need to find environmentally sustainable ways to provide energy, the vulnerability of numerous economies to price volatility and disruptions of fossil fuel supplies and increasing dependence on the Middle East, where two-thirds of the world's oil reserves are concentrated.

Large-scale use of gas and oil in Europe's future energy mix raises serious geopolitical concerns. Europe may negotiate with oil and gas suppliers, but the European economy will nonetheless remain vulnerable to sudden sharp rises in oil and natural gas prices.

In 1997, the European Union (EU) signed the Kyoto Protocol, which sought to achieve an overall reduction of 8% in Greenhouse Gases (GHG) emissions during the period 2008-2012, compared to the emission levels of 1990. However, by 2002, the 15-member EU had managed to reduce its combined emissions by only 2.9%, and the current trend suggests that emissions will increase. Climate change is a long-term challenge for the international community; and the objectives mapped out in the Kyoto Protocol are simply the first stage. Thus, the EU recently established a 50% emission GHG reduction target for the year 2030 and an 80% reduction target for the year 2050.

The fact that nuclear power generation does not produce carbon dioxide is increasingly relevant to its role in the European energy mix. The European Commission (EC) also recognises that Europe cannot make any significant impact on carbon dioxide emissions without relying on nuclear energy.

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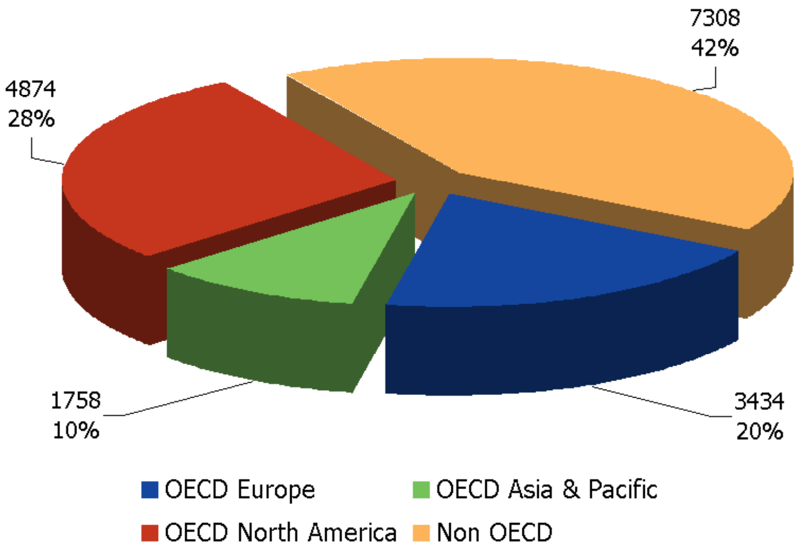
[1] Within this study the terms "Europe" and "European" may have various meanings. The objective of the Working Group created by the WEC–Europe study group was to cover pan-European issues, which are of importance and of common interest to all European countries. However, the background for such a task in terms of existing plans, technological experience, R&D programmes and cooperation between the participating countries is not uniform. Therefore when various specific topics are discussed, different levels of reference are mentioned: in some cases documents and data related to the former 15-member EU are referred to, in other instances the enlarged 27-member present-day EU is involved, and in general issues, the largest circle of 37 European countries is considered. As far as possible this is done explicitly.

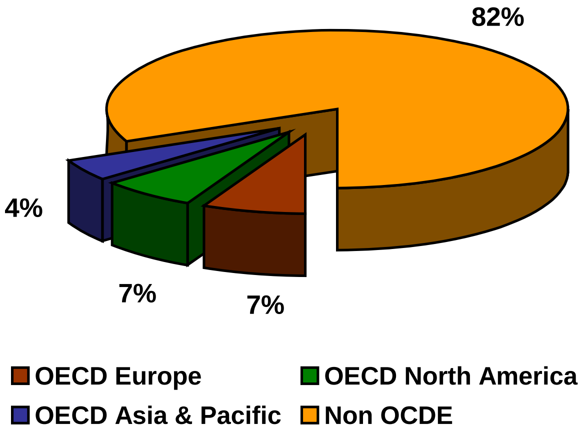
Figure 1.1
World CO_2 emissions by area (Data in Mt CO_2 year 2004)



Source: IEA data, 2004

In support of these commitments, and with the objective of promoting public debate, the EU published the Green Paper "A European Strategy for Sustainable, Competitive and Secure Energy" in March 2006. Its objectives were to guarantee security of supply, reduce the environmental impact of energy use and production, reduce energy demand through savings and efficiency and, in relation to supply, double the contribution of hydro and other renewable energy sources to 10% of global primary energy consumption by the year 2012.

Figure 1.2
World population distribution



Source: OECD data, 2004

Fossil fuel prices are another reason to maintain nuclear power as an option in the future European energy mix. The use of nuclear power for electricity generation could help reduce both EU dependence on energy imports and the price volatility of electric power, since the price of nuclear power is barely linked to the price of fossil fuel. Nuclear power remains one of the most reliable sources of supply for base-load electricity.

In its latest publication “Energy Policy for Europe” published in January 2007, the European Commission stressed that nuclear power production must be considered as an option to reduce CO_2 emissions and to meet the targets of the Kyoto protocol.

Lifetime extensions of nuclear plants, capacity increases or operating licence renewals can add to the competitiveness of the current fleet by reducing lifetime costs and adding low cost output. In addition, if carbon dioxide emissions were ever included in cost assessments, nuclear could be even more competitive: even if quantifying the external costs of energy sources is notoriously difficult and controversial, it is widely acknowledged that coal, oil and even gas have higher external costs than nuclear.

Since 2000, the EU has approved various legislative measures aimed at promoting efficient energy technologies. Energy efficiency is one of the six priority arias of the EU-energy strategies and the EU-Green Paper issued in March 2006 suggested that energy efficiency improvements might significantly contribute to the achievement of all three core objectives, namely competitiveness, security and sustainability. A concrete action plan was adopted in 2006, with a target of reducing the EU’s energy use by 20% compared to the projections for 2020 including savings in the mobility sector.

A key to achieving the Green Paper supply security objectives is the opening of internal energy markets throughout the entire European Union. In the EU countries, traditional gas and electricity supply monopolies, operating at regional or national levels, have been limiting both domestic and industrial customers’ right to choose service suppliers or services.

Since the mid 1990’s, the EU has gradually introduced liberalised energy supply markets, removing barriers to entry for new suppliers and promoting consumer choice, first for industrial and commercial consumers in 2004 and for households in 2007. The objective is to create a single market, whereby competition exists in all EU countries at all customer group levels.

On 1 May 2004 and on 1 January 2007, twelve new countries joined the EU, bringing the number of EU Member States producing nuclear power to 15 out of the total 27 and the total number of reactors operating in the EU from 136 to 154. The share of nuclear power generation rose by 8.2% to more than 31% of total generation. In the pan-European group of 37 countries, the total number of operating nuclear reactors is 204, generating some 26% of total electricity, compared with 55% by conventional thermal plants, 16% by hydroelectric plants and almost 3% by renewable energy sources (principally wind energy).

1.2 Overview of the Current Electricity Production in Europe[2]

As of 31 December 2004, the installed generating capacity of Europe totalled 1,045 gigawatts (GW), some 599 GW (57%) whereof was fossil fuel fired, 228 GW (22%) was hydro, and 172 GW (17%) was nuclear.

Two-thirds of installed fossil fuel fired generation capacity in Europe is now found in five countries (Russia, Germany, UK, Italy and Spain). In terms of installed nuclear capacity, France has the largest concentration (57% or 63 GW), second is Russia with nearly 22 GW closely followed by Germany (20 GW), Ukraine (13 GW) and the UK (12 GW).

The development of low cost gas fields in the North Sea and greater sensitivity to the environment led to the development of lower-emission technologies. Investments over the last fifteen years have focused on natural gas combustion and renewable resources and recently there has been considerable investment in combined cycle gas turbine (CCGT) plants. About 50% of European gas combustion capacity is in the UK and Italy (around 23 GW each). Germany has 17 GW. Natural gas constitutes 57% of the total installed capacity in the Netherlands, 41% in Ireland and 30% in Denmark.

There are very few oil-fired power plants in Europe (9% of total capacity), mostly in Italy, France and the UK. Renewable resources represent a significant share of investment and interest in terms of new capacity, but do not represent a great share in the generating mix.

Electricity generation in Europe in 2004 was around 4,402 terawatt hours (TWh). Some 54% (2,387 TWh) of this was generated by fossil fuel combustion and about 28% by nuclear power.

Historically, fossil fuels are used predominantly in electricity generation in countries with domestic fossil fuel production such as Russia (oil and natural gas), the UK (oil, gas and coal), Germany and Poland (mostly coal and lignite). A clear exception is Italy, which produces more than 75% of its electricity with imported fossil fuels.

Electricity from renewable sources in 2004 was 4% of total European generation. Germany accounted for nearly 36% of this total.

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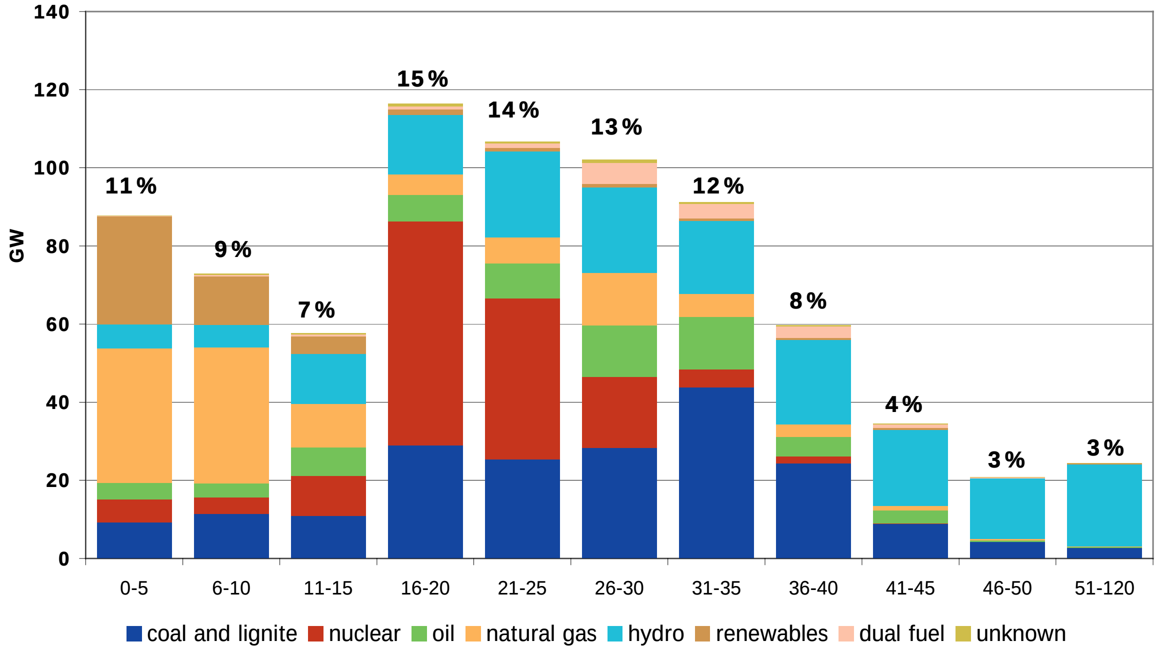
[2] For the data contained in this chapter, please refer to Appendix A.

1.3 The Age Factor

Nearly 30% of Europe's generating capacity is now more than thirty years old. The breakdown of installed capacity by plant vintage (See Figure 1.3) reflects the technological history of Europe's electricity industry. The oldest installations are hydroelectric. Following these in age are coal-fired plants, most of which date from the 1960s to 1990, and are now between 16 and 40 years old. In the 1970s, nuclear power started up, reaching a peak between 1980 and 1990, followed by a period during which development was halted. From the 1990s onwards, natural gas and renewables became more important. Renewable resources (mainly wind energy) have become especially popular over the last decade.

Figure 1.3
Breakdown of European power generation capacity by age
(as of 31 December, 2004)



Source: Utilities Database Institute

Figure 1.3 also reflects the effects of the oil market shock of the early 1970s and the impact of the Chernobyl accident of 1986.

Some hydroelectric plants are extremely small and nearly 20% of such installations in Italy, France and Spain are more than 50 years old. For such plants (at least for those known as 'run-of-river' plants), ageing is not a serious problem, unlike other generating technologies.

Coal and nuclear power plants account for more than 70% of all power plants that will be at least 30 years old in 2020. Replacement of more than 50% of the current electricity installations must be addressed from as early as 2010. The question of replacing capacity will first affect coal combustion and later nuclear energy. Specifically, replacing the coal capacity with cleaner forms of power generation will probably bring economic advantageous. Alternatives to replacement include termination of production, extension of operating licences or radical renovation.

Installed coal-fired capacity in Europe is about 200 GW, with Germany, Poland and the UK accounting for nearly 60% of the total. The proportion of plants currently more than 30 years of age in these three countries is around 49%.

This problem is particularly significant in the UK, where 23 GW (nearly 80% of installed coal capacity or 27% of total installed capacity) is older than 30 years. The implications of this and other factors for the future of nuclear power and electricity generation are elucidated in the document drawn up by the current Blair government, "Creating a Low Carbon Economy".

For Poland and Germany, this aging problem is also significant. In Poland, plants more than 30 years old account for 41% of coal combustion capacity (37% of the total capacity). In Germany, plants in this age range account for 15% of the total and 36% of the installed coal combustion capacity.

However, there are no serious power plant renovation problems for natural gas fuel combustion, and much of the present capacity fuelled by other sources will be replaced by other sources. Much investment has been made in renewables and a number of plants must soon be either replaced or significantly renovated.

A commercial lifetime of approximately 40 years has usually been estimated for nuclear power plants, although there is the possibility of revision and extension of operation.

Starting now, Europe will have to make some important decisions about its future generating capacity. These decisions will be influenced not only by economics, but also by environmental policy. Over the next 10 – 15 years, coal power plants may very well face carbon taxes in some countries.

1.4 Key Issues Raised by the Current Energy Mix

Global energy demand is set to rise substantially during the 21st century. This expectation is based on three factors: the drive to raise living standards in the developing world, continued population growth, and economic expansion and greater industrialisation that improve the standard of living but require additional energy.

While the demand for electricity is growing faster than energy demand, fossil fuel combustion is recognised as a major cause of environmental damage. The release of greenhouse gases (GHG) from burning coal, oil and gas is seen as a major contributor to global warming. Projections for the future role of nuclear power in this context vary widely depending upon the assumptions. These different assumptions highlight factors influencing the future of nuclear power, and so it is useful to examine a few such issues.

1.4.1 Carbon Emissions and the Growth in Demand

The first issue is the degree to which global attention remains focused on limiting greenhouse gas emissions and reducing the risk of climate change. The degree, to which fossil fuels or low carbon energy sources are tapped to meet the growing energy demand, will have a major environmental impact.

Nuclear power emits virtually no air pollution or greenhouse gases. The complete nuclear power chain, from uranium mining to waste disposal including reactor and facility construction, emits only 2–6 grams of CO_2 per kilowatt-hour (kWh). This is about the same as wind and solar power, and one to two orders of magnitude below coal, oil and even natural gas. If the existing nuclear power plants in the EU were shut down and replaced with a mix of fossil fuel sources proportionate to existing nuclear power, the result would be an increase of 700 million tonnes of CO_2 emissions per year. That is approximately twice the total estimated amount to be avoided under the Kyoto Protocol by 2010.

With the reduction of carbon emissions as a top priority, both nuclear and renewable sources could have much larger roles to play. In addition, greater effort should be exerted in electricity production; for example, in developing new technologies such as carbon capture and sequestration, electricity storage and distributed generation. The main problem with renewables is that most of them are intermittent and cannot provide base-load capacity needed to replace large fossil fuel plants.

1.4.2 Security of Supply

A second factor is the current emphasis on security of energy supply. The new EU-Green Paper “A European Strategy for Sustainable, Competitive and Secure Energy”, March 2006, estimated that ‘business-as-usual’ growth would increase energy imports from a current 50% share in total energy supply to about 70% in 2030. A similar concern drove nuclear power investment, during the oil crisis of the 1970s. Availability of uranium resources in a country or region is not a necessary pre-condition for nuclear energy security, given the diverse global roster of reliable uranium producers, and the small storage space required for a long-term nuclear fuel supply.

1.4.3 Relevant Nuclear Issues

An important factor concerns the influence that public opinion, including perceptions of risk, have on energy choices. Nuclear energy has long been marked by unease and if about safety and waste.

The failure of the nuclear community to effectively communicate the relative strength of nuclear power compared to other technology sources has contributed to a lack of public understanding, regarding the risks and benefits of nuclear energy. Common misconceptions can be of great influence in shaping public acceptance of nuclear power. The way that a nation balances the risk of a nuclear accident against other factors such as air pollution or dependency on foreign fuel supplies is already a complex matter for public debate. It is important for the nuclear sector to provide comprehensible, accurate information to support that debate, to ensure that the risks and benefits of nuclear technology are understood.

The development of strong international nuclear safety networks over the past two decades has significantly improved nuclear safety. As nuclear power technology continues to spread to new countries, as new reactor designs are developed and put to use, and as the licences of existing plants are extended, it is essential that safety standards, operational practices and regulatory oversight are broadly adapted.

The management and disposal of spent nuclear fuel remains a challenge for the nuclear power industry. The actual amount of spent nuclear fuel produced globally every year (12,000 tonnes) when compared to the 25 billion tonnes of carbon waste released directly into the atmosphere every year from fossil fuels, seems relatively small. In the case of reprocessing spent fuel, only 4% of the original fission products are finally buried, while the remaining 96 % of useful uranium and plutonium can be recycled and reused. Public opinion is likely to remain sceptical and nuclear waste disposal will remain controversial until the first geological repositories are operational and disposal technologies are fully demonstrated.

In the European context, these issues have been addressed by an *ad-hoc* Working Party on Nuclear Safety (WPNS), set up in June 2004 by the Atomic Questions Group as a consequence of the EU Council conclusions on nuclear safety and safe management of spent fuel and radioactive waste. An action plan was established in December 2004.

1.4.4 Physical Security of Nuclear Power Plants

Power plant security has gained priority in recent years. The September 2001 terrorist attacks in the United States led to the re-evaluation of security in every industrial sector, including nuclear power. Both national and international nuclear security activities have expanded greatly. The key solutions for the future large-scale nuclear power industry will also include technological support of non-proliferation regimes, as described in Chapter 4.

1.5 General Remarks

The future of nuclear power in Europe has been controversial for the past two decades, largely as a result of the Chernobyl accident in 1986. Following a prolonged “out in the cold” period, there is a growing for a re-assessment of the role of nuclear power in Europe’s energy mix. The fact that nuclear energy produces virtually no CO_2 emissions, coupled with developments in technology and concerns over the increasing cost and uncertainty of oil and gas supplies, are gradually transforming nuclear power into an attractive prospect.

Europe must meet its rising energy demand without environmental damage, reducing harmful emissions and securing a stable and sustainable energy supply, and without excessive price or availability fluctuations.

Making these decisions on the future energy mix will depend on national goals and priorities, on exploration for new fossil resources, on the development of clean coal and carbon capture and storage technologies, on improving the performance and cost of renewables, energy efficiency or placing greater reliance on imports. The only base-load generation option available today, with low carbon emissions comparable to nuclear power is large hydropower, but its contribution in meeting the energy demand in Europe cannot be much greater than that at present as most of its potential as already been exploited.

ANNEX 1-A

2004 Installed capacity in WEC Europe countries (MWe)

Country	Total	Nuclear	Conventional thermal power plants	Hydro	Other renewables
Albania	1,671	-	226	1,445	-
Austria	14,100	-	5,700	8,000	400
Belarus	7,910	-	7,830	80	-
Belgium	15,680	5,802	8,369	1,416	93
Bosnia Herzegovina	4,341	-	2,301	2,040	-
Bulgaria	9,456	2,722	4,934	1,800	-
Croatia	3,600	-	1,500	2,100	-
Cyprus	988	-	988	-	-
Czech Republic	16,028	3,528	11,500	1,000	-
Denmark	13,639	-	9,899	11	3,729
Estonia	3,340	-	3,300	30	10
Finland	16,456	2,656	10,900	2,900	-
France	111,863	63,363	26,700	21,000	800
Germany	125,431	20,003	67,015	14,604	23,809
Greece	12,224	-	9,126	3,061	37
Hungary	8,306	1,755	6,500	50	1
Ireland	4,463	-	3,701	512	250
Italy	81,511	-	59,632	20,744	1,135
Latvia	2,124	-	600	1,500	24
Lithuania	4,747	1,185	2,652	910	-
Luxembourg	500	-	440	40	20
Macedonia	1,484	-	1,009	475	-
Malta	478	-	478	-	-
Netherlands	20,289	449	19,300	40	500
Norway	28,055	-	255	27,700	100
Poland	34,053	-	33,085	880	88
Portugal	11,852	-	5,262	4,721	1,869
Romania	21,505	655	14,700	6,150	-
Russia	206,063	21,743	139,600	44,700	20
Serbia & Montenegro	9,287	-	5,798	3,489	-
Slovak Republic	7,242	2,442	3,200	1,600	-
Slovenia	2,995	676	1,318	984	17
Spain	61,960	7,585	26,941	18,572	8,862
Sweden	33,550	9,471	5,700	16,137	2,242
Switzerland	17,320	3,220	500	13,200	400
Ukraine	54,011	13,107	36,200	4,700	4
United Kingdom	76,352	11,852	61,700	1,500	1,300
Europe - 37	**1,044,874**	**172,214**	**598,859**	**228,091**	**45,710**

Source: developed by WEC Study Group with inputs from national committees and IAEA

ANNEX 1-B

2004 Electricity Production in WEC Europe Countries (TWh)

Country	Total	Nuclear	Conventional thermal power plants	Hydro	Other renewables
Albania	4.1	0.0	0.2	3.9	0.0
Austria	64.3	0.0	23.4	36.1	4.8
Belarus	25.1	0.0	25.1	0.0	0.0
Belgium	81.5	44.9	33.6	3.0	0.0
Bosnia Herzegovina	9.5	0.0	5.2	4.3	0.0
Bulgaria	37.3	15.5	18.5	3.3	0.0
Croatia	12.9	0.0	7.6	5.3	0.0
Cyprus	3.8	0.0	3.8	0.0	0.0
Czech Republic	78.4	24.8	51.6	1.4	0.7
Denmark	43.5	0.0	35.5	0.0	8.0
Estonia	9.6	0.0	9.3	0.1	0.2
Finland	81.8	21.8	39.6	10.3	10.1
France	546.7	426.8	57.2	58.6	4.2
Germany	570.1	158.4	341.5	20.9	49.3
Greece	52.5	0.0	47.5	4.9	0.1
Hungary	33.0	11.2	21.5	0.2	0.1
Ireland	23.4	0.0	22.3	0.6	0.5
Italy	290.0	0.0	233.7	49.3	7.0
Latvia	4.1	0.0	1.2	2.8	0.1
Lithuania	19.1	13.9	4.8	0.3	0.0
Luxembourg	2.8	0.0	2.7	0.1	0.1
Macedonia	5.6	0.0	4.7	0.9	0.0
Malta	2.1	0.0	2.1	0.0	0.0
Netherlands	94.7	3.6	85.0	0.1	6.0
Norway	105.6	0.0	0.5	104.5	0.6
Poland	154.2	0.0	150.7	3.3	0.2
Portugal	39.5	0.0	25.8	9.9	3.8
Romania	56.9	5.6	34.8	16.6	0.0
Russia	852.4	143.0	544.2	162.4	2.7
Serbia & Montenegro	38.4	0.0	25.0	13.4	0.0
Slovak Republic	28.4	15.6	9.3	3.5	0.0
Slovenia	17.4	5.2	7.9	4.2	0.1
Spain	261.4	63.6	143.1	35.0	19.7
Sweden	148.5	75.0	4.7	59.5	9.3
Switzerland	63.5	25.4	0.0	35.1	2.9
Ukraine	160.1	81.8	69.6	8.6	0.0
United Kingdom	379.3	73.7	294.0	4.5	7.1
Europe - 37	**4401.5**	**1209.8**	**2387.2**	**666.9**	**137.6**

Source: developed by WEC Study Group with inputs from national committees and IAEA

ANNEX 1-C

Key Data on Electricity Production, Energy Dependence and CO_2 Emissions

COUNTRY	No. of NPPs in operation (December 2005)	2004 Electricity Prod. (TWh)	Electricity international exchange (TWh)(1)	External energy dependence (%)	Kyoto Protocol Target (%)(2)	CO_2 emissions (%)(3)
Albania	0	4.1	1.7	N/A	-	-
Austria	0	64.3	5.6	66	-13	+8.8
Belgium	7	81.5	6.4	76	-7.5	+2.9
Bosnia Herzegovina	0	9.5	-0.9	N/A	-	-
Bulgaria	4	37.3	-3.6	N/A	-8	-56
Croatia	1	12.9	5.4	N/A	-5	-11.5
Cyprus	0	3.8	0	99	-	-
Czech Republic	6	78.4	-16.2	26	-8	-24.9
Denmark	0	43.5	-8.6	41	-21	-0.4
Estonia	0	9.6	-1.4	30	-8	-55.2
Finland	4	81.8	4.9	52	0	6.8
France	59	546.7	-66	50	0	-1.9
Germany	17	570.1	-6.7	60	-21	-18.5
Greece	0	52.5	2.1	70	+15	+26
Hungary	4	33.0	7	58	-6	-31
Ireland	0	23.4	1.2	90	+13	+28.9
Italy	0	290	45,6	83	-6.5	+9
Latvia	0	4.1	2.5	55	-8	-62.8
Lithuania	1	19.1	-8.2	43	-8	-65.7
Luxembourg	0	2.8	3.5	99	-28	-19.8
Macedonia	0	5.6	0.1	N/A	-	-
Malta	0	2.1	0	100	-	-
Netherlands	1	94.7	17	33	-6	+1.1
Norway	0	105.6	7.9	N/A	+1	+6.1
Poland	0	154.2	-10.1	11	-6	-32.2
Portugal	0	39.5	2.8	84	+27	+40.5
Romania	1	56.9	-2.9	N/A	-8	-48
Russia	31	852.4	-10	N/A	0	-38.5
Serbia & Montenegro	0	38.4	3.1	N/A	-	-
Slovak Republic	6	28.4	-2.4	65	-8	-28.4
Slovenia	1	17.4	0.2	50	-8	-1.1
Spain	9	261.4	1.2	78	+15	+40.5
Sweden	10	148.5	12.8	37	+4	-3.5
Switzerland	5	63.5	-2.4	N/A	-8	-1.7
Ukraine	15	160.1	4.9	N/A	0	-47.4
United Kingdom	23	379.3	2.1	12	+12.5	-14.5

(1) Electricity exchange balance with foreign countries. Negative figures mean exporting balance
(2) Kyoto Protocol reducing emissions target in period 2008-2012 with respect to 1990 level
(3) CO_2 emission variation rate in 2004 with respect to 1990 level

Source: developed by WEC Study Group with inputs from national committees and IAEA

CHAPTER 2: OPERATING NUCLEAR POWER PLANTS IN EUROPE

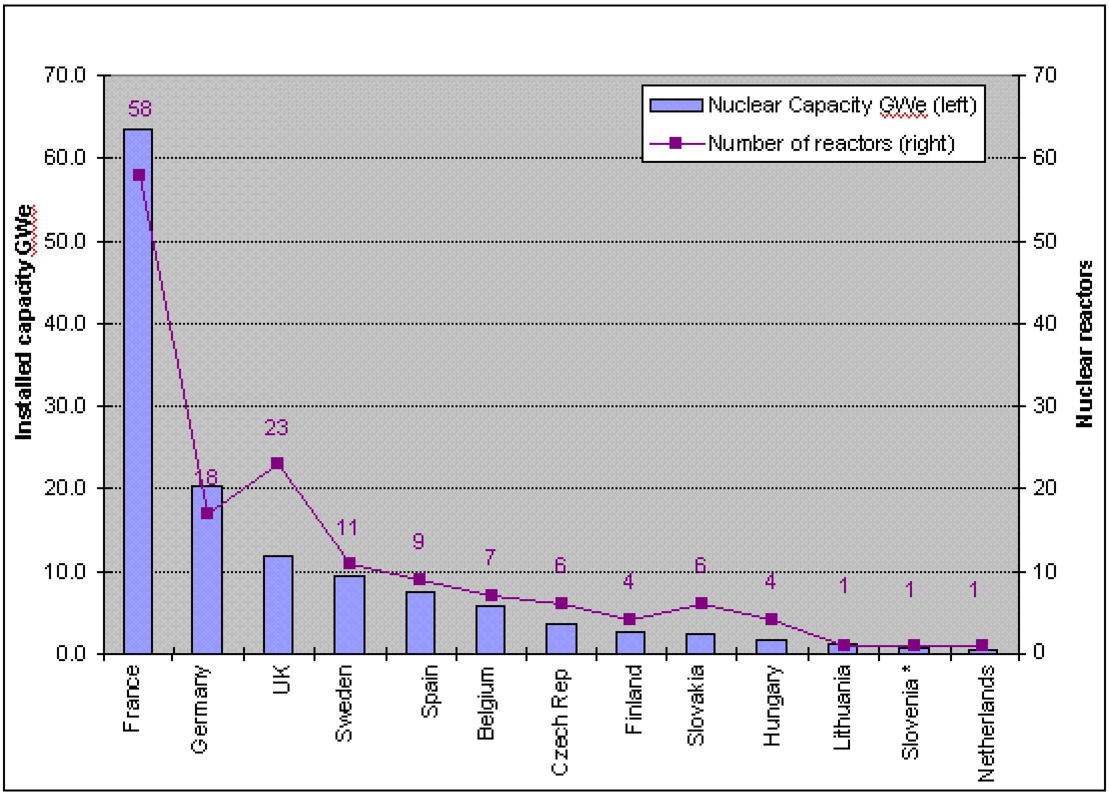
2.1 Status of Nuclear Power Plants in Europe[3]

2.1.1 Installed Nuclear Capacity

2.1.1.1 European Union (EU)

As of December 31st, 2004, there were 148 nuclear power reactors in operation in the EU member states, with a total net capacity of 131 Gigawatts (GWe). These reactors have been installed over the last four decades and have accumulated a total of approximately 4000 reactor years of operation without a major incident; whilst exhibiting increasing levels of production performance. France has the highest number with 58 units (63.4 GWe), followed by the United Kingdom (UK) with 23 units (11.9 GWe) and Germany with 18 units (20.3 GWe). Nuclear power is used for electricity production in 13 out of the 25 EU Member States.

Figure 2.1[4]
Total number installed (net nuclear capacity in Gwe) versus the number of nuclear units by country for EU-25 as of December 31st , 2004



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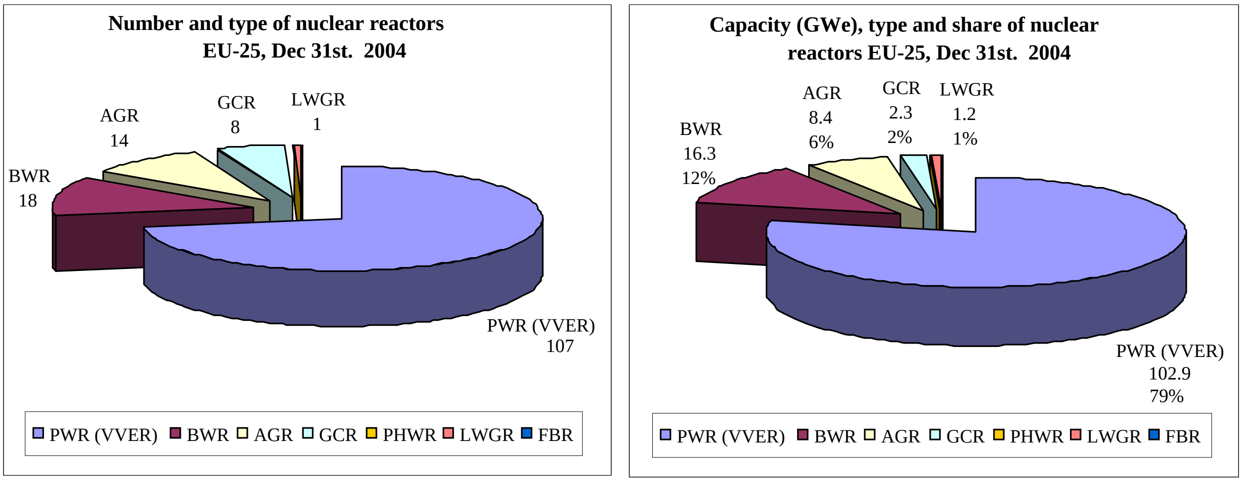
[3] as of December 31, 2004

Figure 2.2[4]
Number of reactors (left) and installed capacity by type (right) in the EU-25 as of December 31st, 2004



PWR	*Pressurised light-water-moderated and cooled reactor (referred to VVER in the former Soviet Union)*
BWR	*Boiling light-water-cooled and moderated reactor*
AGR	*Advanced gas-cooled, graphite-moderated reactor*
GCR	*Gas-cooled, graphite-moderated reactor*
PHWR	*Pressurised heavy-water-moderated and cooled reactor*
LWGR	*Light-water cooled, graphite-moderated reactor - RBMK*
FBR	*Fast breeder reactor*

The majority of nuclear reactors, which comprise 107 units, are the pressurised light water type (PWR), with an absolute capacity of 103 GWe, which accounts for 79% of the total nuclear power in the European Union (EU). This type of reactor is used in all the EU member states apart from Lithuania where the LWGR type reactor is exclusively operated.

The boiling light-water reactor (BWR) has the second largest quota with 18 units and a capacity of 16.3 GWe. The BWR generates approximately 12% of the total nuclear power in the EU and is operated throughout Sweden, Germany, Spain and Finland.

With 14 units (8.4 GWe) and 8 units (2.3 GWe) the advanced gas-cooled (AGR) and the gas-cooled (GCR) type reactors come in third and fourth position respectively. The gas-cooled reactors are solely operated in the UK.

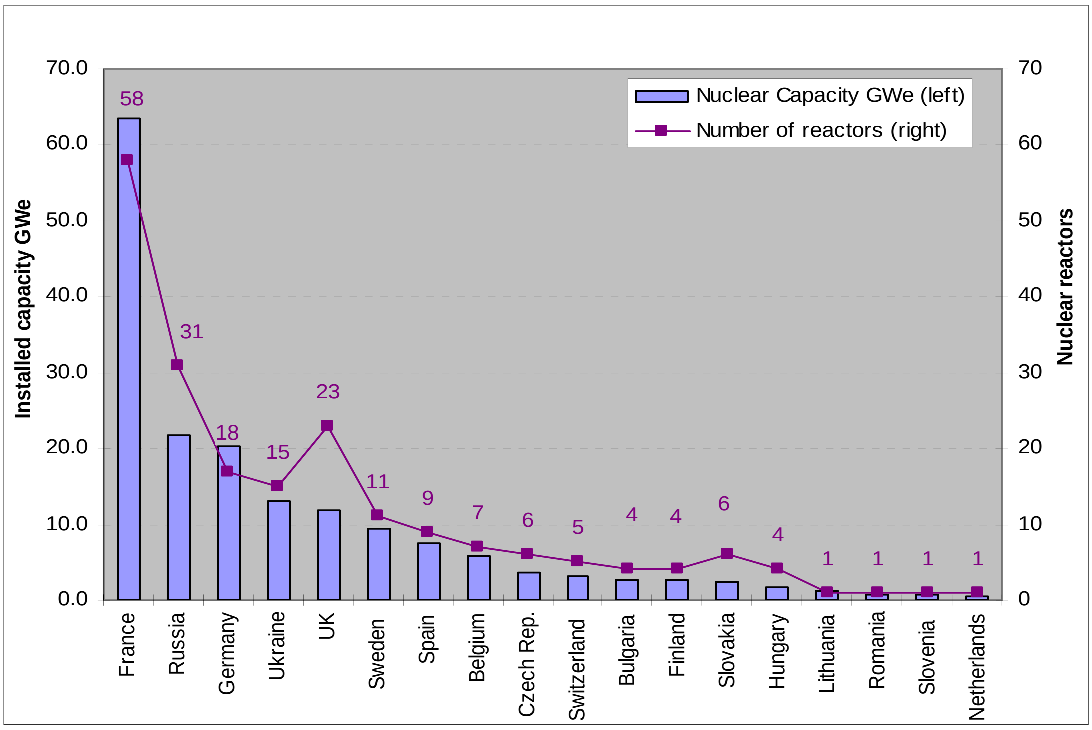
2.1.1.2 Europe

As of Dec 31st, 2004, there were 204 nuclear power reactors in operation in Europe, with a total net capacity of 173 GW. Within Europe, after France comes Russia in second position, with installed capacity of 21.7 GWe, followed by Germany (20.3 GWe), Ukraine (13.1 GWe) and the United Kingdom (11.9 GWe).

The aggregate figures (see Graph.4.0) covering all the WEC-European nuclear operators (EU + others) showed that the scale of nuclear technologies by type were ranked in a similar order to those of the EU space: the pressurised light-water type reactors (PWR) again represented the majority of the total installed capacity (130.7 GW e or 77%) and were in operation in 16 out of the18 countries owning nuclear units.

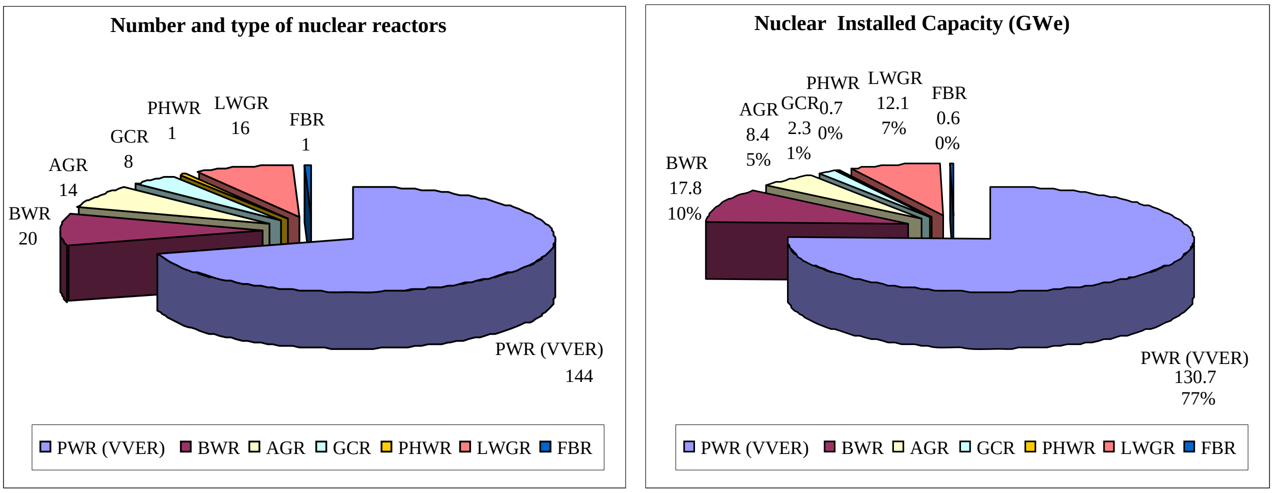
Figure 2.3[4]

Represents the total installed net nuclear capacity in GWe vs the number of nuclear units by country in all of Europe on 31 December, 2004



The boiling light-water type reactor (BWR) is in second position (17.8 GWe or 10%) whilst in third position is the light-water cooled reactor (LWGR) used in Russia and Lithuania (12.1 GWe or 7%); followed by the advanced gas-cooled (AGR) and gas-cooled type reactors (GCR). The latter two types of reactors are installed within the United Kingdom with 8.4 Gwe (5%) and 2.3 GWe (1%) respectively. France and Russia each possess one unit of the fast breeder type reactor (FBR). The only pressurised heavy-water reactor (PHWR) in Europe is located in Romania (See Figure 2.4).

Figure 2.4[4]
Represents nuclear fleet capacity in all of Europe on 31 December, 2004

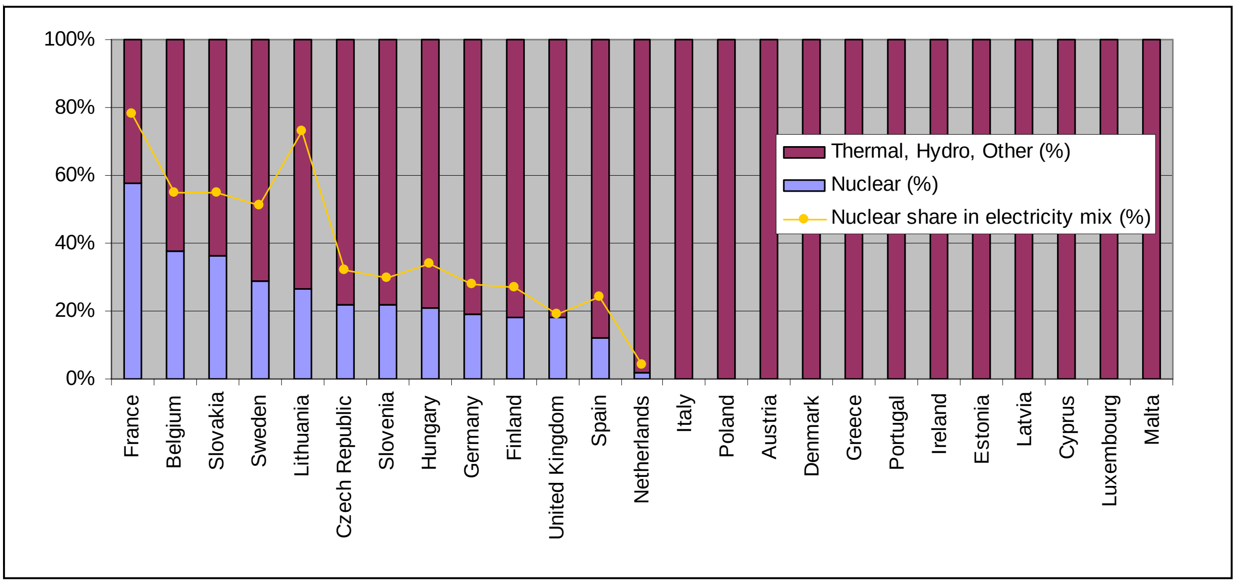


2.1.2 Nuclear versus Total Generating Capacity

2.1.2.1 European Union (EU)

As of the end of December 2004, the total installed generating capacity in the European Union was 665,2 GWe. The nuclear power reached around 20% (131.1 GWe) of all the generating capacity in the EU member states and thus, supplied 31% of total electricity generation. France has the highest nuclear share - 57% of total generating capacity.

Figure 2.5[4]
Represents the share of nuclear power (%) in total generating capacity and electricity production for EU-25 on 31 December 2004



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[4] All graphs in this section were developed by the WEC Study Group with inputs from national Member Committees and IAEA.

2.1.2.2 Europe

Within WEC Europe, the nuclear generating capacity reached almost 17% (173 GWe) of the total installed capacity (1,035 GWe) and it delivered 27.5% of overall electricity production (see Annexes A and B, to chapter 1)

2.2 Economics and Performance of the Existing Nuclear Power Plants

The following economic assessment of nuclear power is based upon generating technology, currently used in operating nuclear reactors and assumes base-load production.

2.2.1 Introduction

The total generation cost includes three major components: capital, operating and maintenance costs (O&M) and fuel. These costs vary significantly, both in absolute and relative value and from country to country. International cost comparisons are difficult because of country-specific factors and a lack of a common method for its calculation. Such comparisons are further complicated by variations in exchange rates. Over the past 5 years, the United States' dollar (USD) has moved against the Euro in a series of rapid changes; the exchange rate EUR/USD has varied from 0.90 cents to about 1.40 during this period.

In many countries, including the EU member states, these costs are usually considered confidential and are not easily available. By contrast, in the US, reports of production costs (O&M plus Fuel) by the nuclear operators are filed with the Federal Energy Regulatory Commission (FERC). The figures on production costs can be found in 'Nucleonics Week' and are based on FERC information for the 103 operating plants. For example, in 2004 the average production cost for the US nuclear fleet was 1.68 cents per kWh, down from 3.63 cents in 1987 (See Annex 2-C). This downward trend is mainly attributed to increased availability, together with reduced fuel costs. Nuclear power plants have been declining in most countries, over the past decade.

Similar results, in terms of increased availability (See Annex 2-D), should be true for the EU, with more than 150 power reactors, but this cannot be fully verified. Nonetheless, the following section provides at least a partial and anecdotal picture of the economics of nuclear power in Europe.

2.2.2 Structure of Generation Costs

2.2.2.1 Capital Costs

The capital cost of nuclear power plants depends on plant size, multiple unit sites, design improvement, standardisation, and performance improvement. France, for example, bases its large nuclear power programme on standardised units. For a nuclear unit, approximately one-half of the total generation cost represents the return on investment. The capital costs are accounted for through depreciation. Thus, if the plant lifetime is increased from 40 to 60 years, capital amortisation could be also extended, resulting in lower annual capital costs. However the majority of operating NPPs have been fully amortised, so further discussion refers to operating costs only.

2.2.2.2 O&M Costs

Operation and Maintenance (O&M) costs are influenced by technical performance of the nuclear plants and by safety regulations and manpower costs in different countries; therefore, O&M costs vary significantly in country comparisons. Lowering or at least stabilising O&M costs has been achieved, through increased operating experience and more efficient management

Availability is the main driver for reducing nuclear production costs; increased availability results in an increase in the production of electricity, and hence greater output over which to spread fixed costs.

Since 1990, efficiently operated and managed nuclear plants have increasingly achieved higher availability factors, with the same or greater levels of safety. From 1990-2005, availability factors in the US rose from 71% to 90%; whereas lower increases occurred in the EU-15 (from 74% to 84%). Consolidation of the nuclear industry and improved leadership at nuclear plants are considered among others, contributing factors to improvements in the US. Average availability factors now commonly approach 90% in the US and 80% in the rest of the world. Availability factors in Finland are close to 95%. Availability of Russian plants has also increased dramatically from 66% (1993) to 78% (2004). (See ref. [6])

These increases in availability factors of nuclear plants are significant, since the additional electricity production from 1994 to 2004, is equivalent to adding 18 large (1000 MWe) reactors to the US fleet, and 22 large units for the whole of Europe. Moreover, O&M costs per kWh have fallen as availability factors have increased.

The most important technical factor, which has an impact on nuclear fuel costs, is the level of fuel burn up. Increasing fuel burn up, thanks to the advanced fuel designs has contributed significantly to the reduction in the fuel cycle costs. Higher burn-up also permits longer fuel-load cycles (i.e., longer intervals between refuelling and hence, fewer and shorter planned outages). This also increases plant availability. Shorter outage and refuelling periods are occurring worldwide and the median duration of refuelling outages of light-water reactors (LWRs) continues to decrease. The average duration of refuelling outage, after a slight increase in 2001, is again moving downward. Worldwide, the shortest refuelling outage duration is the Olkiluoto Unit 2 in Finland, which takes seven days. The US record is 15 days at Browns Ferry Unit 3.

A number of insurance costs related to nuclear operations are usually considered part of O&M. One of these costs is third party liability, compulsory for nuclear power plants and stipulated by international conventions. The annual cost for this insurance is of the order of 0.05 Euro/MWh and is likely to increase in the future. Insurance of property damage is optional, but most reactors have elected to have it. The premium per year on the plant and reactor is of the order of 0.2 Euro/MWh for property damage.

Available data on O&M costs show a range from 0.46 to 0.68 US-cent/kWh for four countries in Western Europe (France 0.46, Finland 0.48, Germany 0.65 and the Netherlands 0.68).

O&M costs may fall further. However, they may also increase as plants age or if large refurbishment programmes are implemented. They are also sensitive to regulatory requirements.

2.2.2.3 Fuel Costs

Nuclear fuel costs, including spent fuel management are on average 0.5 US-cent/kWh. Fuel accounts for a relatively small part of total nuclear generation cost, approximately 20%. In recent years, fuel cycle costs have decreased significantly, leading to reduced fuel costs for all types of nuclear power plants globally. Moreover, technical improvements such as the introduction of advanced fuel designs can allow higher burn up levels, leading to efficiency gains and a reduction in costs. It is estimated that a 40% reduction in nuclear fuel cycle costs has occurred since 1990, in real terms. For example, nuclear fuel costs in the US have fallen from 1.28 cents per kWh in the mid-1980s to only 0.44 cents per kWh today (See ref. [2]).

Uranium prices have suddenly soared from 10 US$/lbU$_{308}$ in 2002, to more than US$50 (86 €/kg) (See Annex 2-G) in 2006. This trend is set to continue, until new mines are opened; however, the impact on generation cost is small. For a large pressurised water reactor (PWR), in absolute terms, this five-fold increase in uranium price will only double the fuel cost (expressed in US-cents) from 0.25 to 0.50 cents/kWh, a 10% increase in the total generating cost (assumed here to be 2.5 cents/kWh).

The reduction in O&M and fuel costs (including decommissioning and waste) has been substantial over the past decade. In Spain, generating costs have fallen in the 2000-2004 period (See Annex 2-E). In the US, these costs have fallen 44% between 1990 and 2003, (See ref.[2]). In France, a cross comparison of production costs of EdF plants (58 units) and US plants (103 units) was published by EdF, (See Figure 8 (ref.[10]). This shows that in 2001, EdF production costs (O&M + fuel) of approximately 1.4 Euro-cent/kWh was exactly the same as for the US average (1.6 US-cent/kWh, equivalent to 1.4 Euro-cent/kWh).

In France, EdF generating costs never exceeded 2.2 Euro-cent/kWh in the period 1981-2002. Direct operating costs in the early 1990s were as low as 5 French centimes (0.7 Euro-cent) per kWh, and availability increased from 70% to 81%. The efficiency of French plants is attributed in part to several factors:

- Size increase and the standardisation of nuclear power plants have had positive cost effects. Due to standardisation, full advantage can be realised from experience-feedback from plants in operation. It allows economies of scale in spare parts management, document consistency, maintenance programmes, simulators for the training of operators, etc.;
- O&M costs per unit are 20% to 30% lower, when shifting from 900 MW to 1300 MW units; and
- The average labour cost per unit is 17% lower, when the site hosts 6 units instead of 2 units.

2.2.2.4 Other Costs

Besides direct production costs, nuclear plants must cover other costs. These include:

- **Decommissioning Costs**

A recent study on decommissioning costs was conducted by the Organisation for Economic Cooperation and Development (OECD) Nuclear Energy Agency (See ref.[11]). Decommissioning costs considered include: dismantling the nuclear power plant, waste treatment and disposal of all types of radioactive waste, security, site cleanup and project management. Dismantling and disposal represents a major share, each accounting for approximately 30% of the total decommissioning cost.

The 26-country study included, a variety of reactor types and sizes. The cost data analysis resulted in the following average decommissioning costs and standard deviation (in USD/kWe):

Plant type	Average	Std. deviation
PWR	320	195
VVER	330	110
BWR	420	100
PHWR/CANDU	360	70
GCR	> 2500	-

Source: Organisation for Economic Cooperation and Development (OECD) Nuclear Energy Agency

National variations in policy and strategy, lead to variations in decommissioning costs. The average cost estimates are in the range of 320 to 420 USD/kWe for most reactor types. In general, gas-cooled reactors (GCR) are more expensive to decommission than water-cooled reactors, because they must dispose of large quantities of graphite.

The cost for dismantling the older, smaller 160MWe reactor at Zorita in Spain has recently been estimated by Union Fenosa, at 135 M Euro (i.e., 850 Euro/kW) and the dismantling of the German plant Obrigheim was estimated at 1,400 €/kWe (357 MW). Dismantling in Germany is more expensive especially for small plants.

- **Waste Management Costs**

Anticipated waste management costs are important in setting aside financial provisions for nuclear power plants. Since no final repositories exist at present for all types of radioactive waste, cost estimation is subject to uncertainty. It is also often difficult to interpret published cost figures for waste management or to compare estimates from different sources.

Nonetheless, most countries impose some form of financial requirement on nuclear facilities to cover the eventual cost of waste disposal, however uncertain this may be. In the US, for example, consumers pay 0.1 US-cent/kWh of electricity from nuclear power to the Federal Nuclear Waste Fund to finance the Department of Energy’s (DOE) repository project. More than 24 billion dollars have been committed to the fund since 1983; it will be used to develop and licence a repository at Yucca Mountain, in the state of Nevada.

In Sweden, nuclear utilities have paid a fee to a Nuclear Waste Fund (NWF) since 1986. The fee covers both waste management and decommissioning costs. On average, the fee has been in the range of 0.06 to 0.2 Euro-cent/kWh.

- **Taxes**

In some countries (France, Sweden), nuclear power facilities have a special tax. In Sweden, the nuclear tax is based on thermal power installed and thus independent of production. The tax is 10,200 SEK or 1100 EUR (9.2 SEK/EUR) per MW thermal capacity, equivalent to 5 Euro/MWhe. It increases the cost of nuclear power by approximately 400 million € per year for the ten operating reactors.

2.2.3 External Costs

Nuclear power produces environmental benefits; it is a CO_2-free source of electricity and generates few external costs. The European Community conducted a study on external costs (termed ExternE) in 2001 (See Annex 2-A); results are in Annex 2-B. A recent study by the UK Royal Academy of Engineering confirms these results. (See ref.[4]).

2.2.4 Conclusions

Nuclear generation costs are decreasing with increased output and for depreciated plants are now competitive with other generating technologies. The sum of O&M and fuel costs for the EU-fleet of reactors is expected to decrease further as availability increases and more kWh are produced per unit.
New investments are underway for upgrading existing plants, lifetime extensions to 60 years, and for power uprating. The marginal generating costs of such projects are roughly only a third of that for new plants. Efficiency gains in the fuel cycle have also helped to reduce generating costs, with higher burnups offsetting higher uranium prices.

However, generating costs are sensitive to regulatory requirements, such as inspections and safety improvements. Regulatory environmental and safety oversight have been streamlined and the licensing processes made more predictable, but they may increase as plants age.

2.2.5 References

[1] “Projected Costs for Generating Electricity”, OECD/IEA NEA, 2005
[2] “The New Economics of Nuclear Power”, WNA Report, 2005
[3] “Sustainable Development in Practice”, FORATOM, 2005
[4] “The Cost of Generating Electricity”, The Royal Academy of Engineering, 2004
[5] “The Long-Term Sustainability of Nuclear Energy”, WNA Energy Review, 2005
[6] “Nuclear Energy Trends”, IAEA, September 2005
[7] “The Economics of Nuclear Power”, Uranium Information Centre, May 2005
[8] “An Ocean Apart”, Stricker & Leclerq (Revue Générale du Nucléaire), December 2004
[9] “Nuclear Fuel: Key Factor for the Competitiveness of Nuclear Energy in Spain”, WNA Symposium, 2003
[10] “Les performances comparées des parcs nucléaires en exploitation des Etats-Unis et d´Electricité de France“, Stricker & Leclerq (Revue Générale du Nucléaire), 2004.
[11] “Decommissioning Nuclear Power Plants”, OECD/NEA, 2003

2.3 Life Extension and Power Upratings

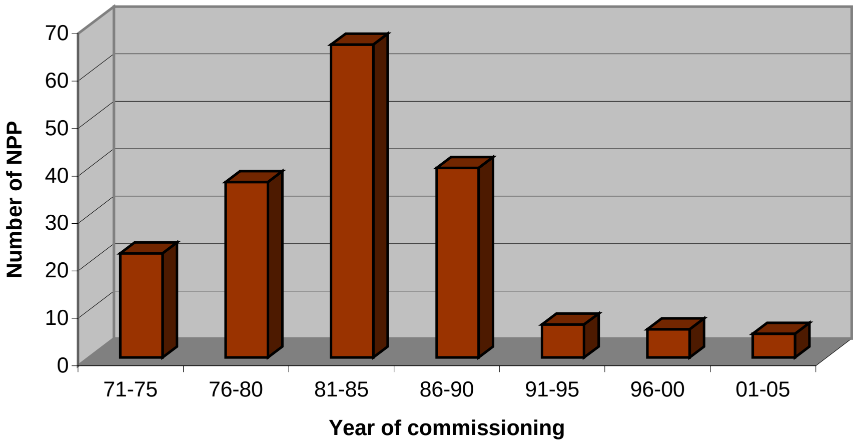
2.3.1 Reactors' age, Licensed Life (Including Extensions Granted or Planned)

Licensed service life of nuclear reactors has been originally planned for up to 40 years. However, it was concluded on the basis of periodic safety reviews, that nuclear power plants (NPP) service life could be extended up to 50 to 60 years. Different countries have different policies, but it is quite common to renew the licence every 10 years, after the NPP is examined and is found to comply with the requirements.

There are 37 licence renewals granted in the US. Twelve applications are currently under review and 27 nuclear power plants have sent a letter of intent to apply for licence renewal.
The number of reactors built between 1971 and 2005 is shown in the table/chart below:

Period	Commissioned Reactors:
1971 - 1975	22
1976 - 1980	37
1981 - 1985	66
1986 - 1990	40
1991 - 1995	7
1996 - 2000	6
2001 - 2005	5
	Total: 183

Figure 2.6
Number of reactors built between 1971 and 2005



Source: Response to a Questionnaire circulated by the Study Group to the countries

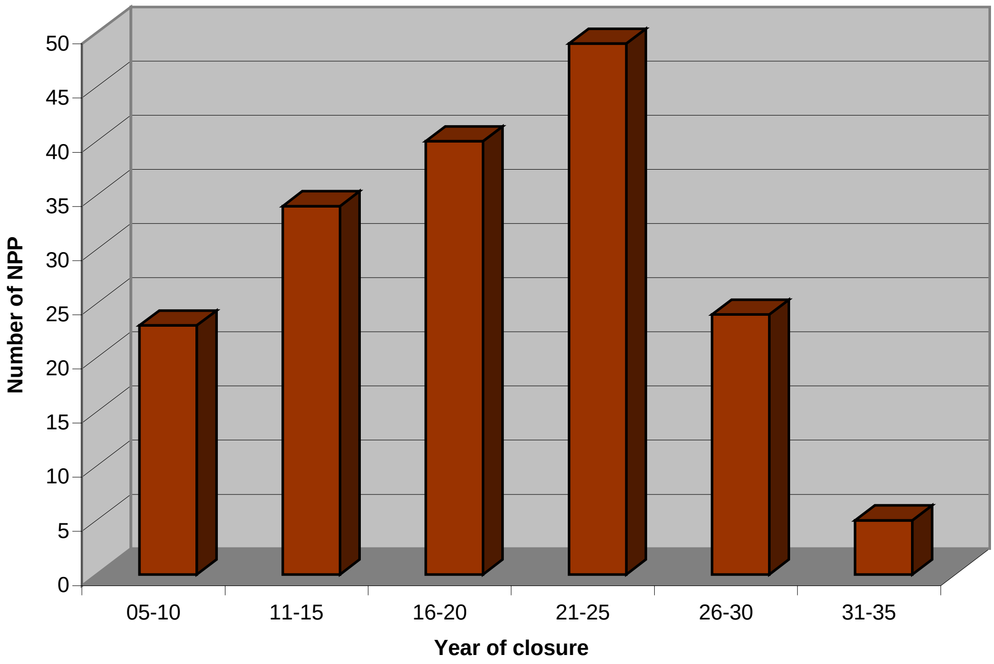
2.3.2 Panorama of Planned Reactors Closure without Life Extensions

An overview of closure of reactors without life extensions is shown, in accordance with the available data. In cases where exact data are not available, the plant lifetime is assumed to be 40 years.

The closure of reactors without life extensions is shown within 5-year periods:

Planned period for shutdown:	**Number of Reactors:**
2005 and 2010	23
2011 and 2015	34
2016 and 2020	40
2021 and 2025	49
2026 and 2030	24
2031 and 2035	5
after 2036	8
	Total: 183

Figure 2.7
Closure of reactors without life extension



Source: Responses to a Questionnaire circulated by the Study Group to the countries as well statistical data provided by the IAEA, Vienna

2.3.3 Relative Value of Existing and Potential Power Increases. Power Uprates that have been implemented, in Progress or Planned

Utilities have been using power uprates since the 1970s, as a way to increase the power output of their nuclear plants.

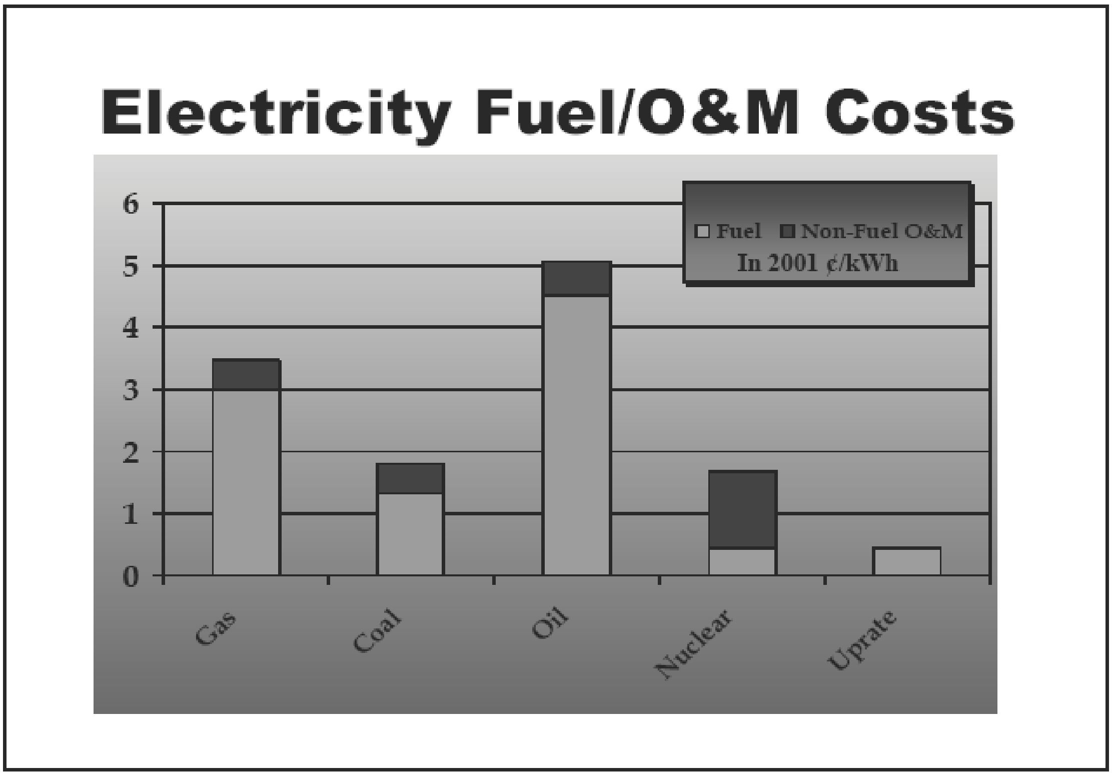
Power uprates can be classified in three categories: (1) measurement uncertainty recapture power uprates, (2) stretch power uprates, and (3) extended power uprates.

1) **Measurement uncertainty recapture power uprates** are power increases less than 2% and are achieved by using enhanced techniques for calculating reactor power. This involves the use of state-of-the-art devices to precisely measure feedwater flow to calculate reactor power. More precise measurements reduce the degree of uncertainty in the power level, which is used by analysts to predict the ability of the reactor to be safely shutdown under accident conditions.

2) **Stretch power uprates** are typically up to 7% and usually involve changes to instrumentation settings. Stretch power uprates generally do not involve major plant modifications; this is especially true for boiling-water reactor plants. In some limited cases, where plant equipment was operated near maximum capacity prior to the power uprate, more substantial changes may be required.

3) **Extended power uprates** are usually greater than stretch power uprates and have been approved for increases as high as 20 percent. Extended power uprates usually require significant modifications to major pieces of plant equipment such as the high-pressure turbines, condensate pumps and motors, main generators, and/or transformers.

Figure 2.8 - Projected costs for electricity generation



Source: OECD/IAE-NEA publication, 2005

Power Uprates in EU-25 + Switzerland

Country	MWe(net) at Start of Operation	MWe(net) at 31.12.2004	Uprate %
Finland	2210	2656	20.18
Switzerland	2899	3220	11.07
Spain	7297	7877	7.95
UK	12692	11920	-6.08
Belgium	5450	5783	6.11
Germany[5]	19847	20643	4.01
Czech Republic	3457	3373	-2.43
Bulgaria	2656	2722	2.48
Lithuania	1500	1185	-21.00
Sweden[6]	8920	9531	6.85
Netherlands	447	450	0.67
Slovenia	632	676	6.96
Slovak Republic	2390	2442	2.18
Romania	645	655	1.55
Hungary	1650	1755	6.36
France	62623	63363	1.18
EU-25 + Switzerland	**135315**	**138251**	**2.17**

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[5] The validity of operating licences for the German plants is unlimited. However, the operation is limited by electricity defined for every plant to be produced. A transfer of electricity production quantities between plants is possible under certain conditions.

Lifetime extensions are not envisaged under the current law.

Power Uprates: capacity was increased at several plants due to higher rates of efficiency following modifications of turbines and/or due to the increase of thermal power.

[6] The power upratings currently planned between 2005 and 2011 for the Swedish plants, amount to a total of 1308 MW.

2.4 Status and Strategies on Radioactive Waste Management and Decommissioning

2.4.1 Introduction

Radioactive waste has become a focus of environmental concerns in connection with nuclear power generation. Radioactive waste is a product primarily of the nuclear power plant operations, but also results from medical, research and industrial applications. All this waste must be handled and disposed in a safe way. The solution adopted for nuclear waste management is to isolate radioactive substances from the biosphere. Radionuclides will decay and, when properly isolated, will never cause harm to the environment.

Radioactive waste from nuclear power plants comes out in small quantities. The generation of electricity from a 1000 MWe nuclear power station produces a few hundred cubic metres of low- and intermediate-level waste (L/ILW) per year and some 30 tonnes of spent nuclear fuel (SNF). There are a number of final repositories in operation for L/ILW in Europe. The final disposal of spent fuel or high-level waste separated from spent fuel is still under development and the first repositories are planned to start operating in some European countries around 2020. When the nuclear power plants are decommissioned and dismantled, mainly L/ILW is accumulated and the annual volume for the EU-25 reached 45,000 m³ while the high level waste (HLW) originating from SNF, reached 400 to 500 m³.

Spent nuclear fuel is temporarily stored at each nuclear power plant site. There are three general approaches to managing the spent nuclear fuel: reprocessing, direct disposal and temporary storage (until a suitable choice of disposal is made). The approach is selected at the national level. Governments usually establish the legal and regulatory framework, define the process of financing and carry out an environmental assessment of the facilities and sometimes implement particular measures.

In general, governments are well informed about radioactive waste liabilities and try to ensure that the cost of managing of waste generated now or in the future will be paid by or recovered from power producers. The government may require the utilities to set up, fund and create a separate organisation that has specific responsibilities for the long-term management and disposal of the waste. Then, the government provides regulations and oversight, and ensures that the funds are spent for the appropriate purposes.

Governments have an essential role in finding solutions for the management and disposal of all radioactive waste, taking into account social and ethical, as well as technical and economic issues.

2.4.2 Inventory of Radioactive Waste and Spent Fuel

Based on the 2006 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Management, the status of the spent fuel and radioactive waste management in the European countries is as follows.

In Germany, at the end of 2004, the total spent fuel produced by 18 power reactors in operation and 11 power reactors under decommissioning, amounted to 11,393 tonnes.

The inventory of radioactive waste from German nuclear power plants, on 31 December 2001 was as follows:

Type of waste	Operating NPP	Decommissioned NPP
Untreated primary waste	7,228 m³	6,889 m³
Interim products	686 m³	2,182 m³
Conditioned waste	13,242 m³	4600 m³

In France, the spent fuel is produced by 58 pressurised water reactors (in the order of 900 MWe - 1450 MWe), all commissioned between 1977 and 1999. EdF, CEA or COGEMA play an important role in spent fuel management, including reprocessing.

At the end of 2004, about 7,200 tonnes of French spent fuel was stored in the La Hague storage site, some 3,600 tonnes in EdF's nuclear power plants and 120 tonnes in the CEA's centres.
The annual production of radioactive waste is summarised below:

Low/Intermediate level waste –short-lived (LILW-SL)	12 000 m³ (75% from fuel cycle and electricity production)
Intermediate level waste –long lived (ILW-LL)	930 m³ (80% from fuel cycle and electricity production)
High level waste (HLW)	155 m³ (100% from fuel cycle and electricity production)

In Spain, spent fuel is currently stored in the pools of operating NPP reactors and at a facility for dry storage at the Trillo site. The spent fuel inventory of the Spanish reactors is between 78 tonnes (Jose Cabrera) and 509 tonnes (Cofrentes).

On 31 December, 2004, the inventory of L/ILW in the Spanish NPPs ranges from 140 m³ (Trillo) to 2980 m³ (Vandellos 1), depending on plant lifetime.

The Russian Federation accumulated about 18,500 tonnes of spent nuclear fuel, held at both the plant sites and reprocessing plants.

In Finland, on 31 December 2004, the spent fuel is stored at Louisa (351 tonnes) and at Olkiluoto (1026 tonnes). The radioactive waste is pre-conditioned, undisposed waste at Loviisa was (1458 m³) and Olkiluoto (506 m³); disposed waste at Loviisa was 1234 m³ and at Olkiluoto waste disposal facilities (4140 m³).

Detailed information about production and inventory of the radioactive waste is included in the European Commission's "Nuclear Safety and the Environment. The Fifth Situation Report - Radioactive Waste Management in the Enlarged European Union, EUR 20653, February 2003".

The following data shows annual production of spent fuel based on the operating experience of the different power reactors in Europe:

Country	Reactor type	Quantity of SNF per GWe/year [tonnes]
Belgium	PWR	20
Finland	LWR	26
France	PWR	19
Germany	LWR	19
The Netherlands	PWR	20
Spain	PWR	20
Spain	BWR	22
Sweden	LWR	21
United Kingdom	AGR	29
United Kingdom	PWR	25
Bulgaria	VVER	28
Czech Rep.	VVER	29
Hungary	VVER	30
Romania	CANDU	145
Slovakia	VVER	27
Slovenia	PWR	22

Annual production of L/ILW of different power reactors in Europe:

Country	Reactor type	Quantity of waste per GWe/year [m^3]
Belgium	PWR	70
Finland	LWR	130
France	PWR	140
Germany	LWR	58
The Netherlands	PWR	100
Spain	PWR	114
Spain	BWR	260
Sweden	LWR	114
United Kingdom	AGR	380
United Kingdom	PWR	190
Bulgaria	VVER	230
Czech Rep.	VVER	300
Hungary	VVER	200
Romania	CANDU	80
Slovakia	VVER	200
Slovenia	PWR	150

2.4.3 Institutional System

2.4.3.1 General Requirements

The institutional framework for the management of any kind of radioactive waste is defined, to include the following:

- An organisational structure with clearly defined responsibilities, and adequate coordination of all involved activities;
- A consistent set of requirements for the technical and legal infrastructure including, resources, funding, liabilities, institutional control, records management and research activities; and
- Provisions for participation by interested parties in decisions and implementations.

There are many different institutional and financial arrangements already established in European countries for radioactive waste management. From time to time, these institutional frameworks are subject to review, especially when new tasks such as the disposal of high-level waste (HLW) and/or spent fuel or decommissioning arise.

The difference in the approaches between countries is likely to emanate from different conditions (including the legislative framework), therefore, a careful adoption of the necessary and appropriate steps is recommended. Nevertheless, consideration of all the existing approaches could be useful in developing future national institutional and financial arrangements for radioactive waste management.

2.4.3.2 Organisational structure

National approaches for defining and classifying radioactive waste, siting and designing waste management facilities, implementing institutional measures for safe disposal, and securing public acceptance of waste management operations and facilities, vary considerably. Many common elements can vary greatly in size and complexity. Typically the following organisations conduct the following functions:

- **Policy/legislation /strategy**

  Organisations responsible for policy-making, legislation, strategy drafting and other decisions that require involvement of government officials (often elected officials) at the national level.
- **Regulatory authorities**

  Organisations (government agencies) responsible for regulation of radioactive waste management.
- **Implementing organisations**

  Organisations (governmental or others) responsible for waste management tasks.
- **Advisory (oversight) body**

  Organisation nominated by the government to advise policy-makers or to supervise technical and scientific activities of the implementing organisation.
- **Fund management body**

  Organisation responsible for the management of funds.

An analysis of the national situations clearly shows that, for waste management, the principle of separation between (1) policy-making and legislation, (2) regulatory activities and (3) implementing activities has been established in most European countries with advanced nuclear programmes. The organisational arrangements for radioactive waste management have recently been or are presently being revised in some countries (e.g. Bulgaria and the UK) to better respond to policy considerations regarding how to handle these issues in the future. Current indications are, that the changes in these countries are likely to go towards direction of a more distinct separation between the three levels.

Financial resource management bodies, where they exist, are a supplement to the basic structure comprising of policy-making, regulatory and implementing activities, and are used specifically to deal with long-term financial management issues.

When analysing the existing organisational structure in a country, internationally recognised standards, the organisation’s particular scope of activities and nuclear industry requirements need to be considered.

The national strategies need to accommodate the local needs and circumstances, whilst demonstrating regulatory compliance. Depending on the extent of nuclear activities within a country; there is a choice between three predisposal strategies:

- Decentralised strategy;
- Centralised strategy; and
- A combination of decentralised and centralised strategies.

The choice of centralised or decentralised strategies for the temporary disposal of radioactive waste depends on the number of generating plants, and the need to concentrate radioactive waste processing and long-term storage in one or two locations in a country.

2.4.3.3 Responsibilities of Waste Generators

The responsibilities of waste generators vary among countries, depending on the waste management strategy and nature and volumes of radioactive waste generated. In some countries, a waste generator may also be an operator of the associated radioactive waste management facilities and have the responsibility for all predisposal radioactive waste management activities. In other countries, the responsibility may be assigned to a special agency, or divided between several operating organisations as defined by the legal and regulatory frameworks. The ultimate responsibilities for financing the safe management and disposal remain with the generators.

2.4.3.4 Responsibilities of National Waste Management Organisations

Usually, a user of radioactive sources or an operator of a nuclear facility is responsible for the management of the radioactive waste generated from their activities. However, experience has shown that some waste management activities, including pre-disposal, could be centralised on a national level to enhance safety, increase efficiency and reduce costs. Many countries have established national centralised waste management organisations, others are still working on this.

The functions and responsibilities of the implementing national organisations vary between countries. In some countries, an implementing organisation has been established specifically for disposal or long-term storage of High Level Waste (HLW) and/or spent nuclear fuel (SNF) pending development of a geological repository (e.g. Finland). In other countries, an implementing organisation has been established with a broader responsibility, including the management of radioactive waste from nuclear applications in the country, decommissioning of nuclear power plants and management of decommissioning waste (e.g. Netherlands, Belgium, Italy, Spain and Sweden).

The responsibilities of the national nuclear waste management organisations include the following:

- Preparation of the national waste management strategy;
- Preparation of the annual activities plan for submission to the coordinating body for approval;
- Ensuring and updating a national database on the quantities and types of waste, including the waste resulted from decommissioning of nuclear and radiological installations;
- Preparation of the procedures and technical standards for all stages of radioactive waste management;
- Collection of institutional waste from various generators in the country, including its processing, storage and disposal;
- Ownership and full liability for the radioactive waste transferred;
- Monitoring and control of all stored waste;
- Record-keeping;
- Development of waste acceptance criteria for submission to the Regulatory Body for approval;
- Coordination and preparation of a feasibility study for siting, design, construction, commissioning and operation of waste repositories;
- Ensuring the physical protection of the final repositories, directly or by third parties;
- Ensuring the establishment of the national repositories for disposal of spent nuclear fuel and high level and long-lived radioactive waste;
- Institutional control and long-term stewardship programmes, if necessary.

If a specific agency has been appointed to manage the radioactive waste in a country, that agency shall also be responsible for managing the interfaces between the different parties: waste generators, waste treatment and conditioning facilities, storage facilities, transport companies and disposal facilities.

The possibility of establishing a national implementing waste management organisation in a country is a strategic issue and it should be explored carefully, while a national strategy is drafted. If a decision in favour of the national waste management organisation is made, its functions and responsibilities should be clearly defined, since that would influence the entire technological strategy.

Types of Implementing Organisations

Part of the National or Central Government Administration

Germany (BfS subcontracted to DBE)

Government-owned Companies

Belgium (ONDRAF/NIRAS)

Bulgaria (SERWM)

Czech Republic *(RAWRA)*

Estonia (ALARA)

France *(ANDRA)*

Hungary *(PURAM)*

Lithuania *(RATA)*

Romania (ANDRAD)

Spain (ENRESA)

UK (NIREX)

Private companies (some are part privately owned)

Finland (Posiva Oy)

The Netherlands (COVRA)

Slovak Republic (Slovak Electric Plc.)

Sweden (SKB)

Switzerland (NAGRA)

The institutional framework for managing radioactive waste has to be updated; it is advisable to review the situation on a regular basis. This could provide a convenient opportunity, to assess whether the institutional framework needs to be upgraded.

2.4.4 Financial and Economic Considerations

2.4.4.1 Funding Arrangements

Since many of the activities associated with long-term management of radioactive waste will take place, several decades in the future (possibly after the generators of the waste have gone out of business), it is prudent to allocate the financial resources that will be needed for future operations. European countries use various financial systems to ensure the long-term availability of financial resources for decommissioning, pre-disposal and disposal. Funds and reserves are the two most common financing systems.

The annual payments to the funds are generally calculated/based on the amount of electricity or waste generated in that particular year (i.e. on the basis of the future liability associated with the waste generated in that year). In general, the following methods are used to collect financial resources:

(1) A levy on electricity rates or a contribution from the waste generator (who collected financial resources through electricity rates);

(2) A fee on kWh.

The amount of the contribution is generally computed by the relevant agencies and officially confirmed by the Government. In most cases, levies are applied only to income derived from electricity generated at nuclear power plants. In most countries that have established funds, the government itself, or a high-level organisation within the government, is designated as the financial management organisation and the government is responsible for developing criteria or guidelines for management of the funds.

On the other hand, in countries where the financial resources are retained internally by the waste generators, the waste generators are responsible for the management of these resources. The annual amount deposited into such reserves are primarily determined by the waste generators themselves, in accordance to national legislation and future estimated liabilities.
The funds are usually managed in a low risk manner (e.g. by depositing them in the national account or investing them in government bonds).

In addition, to collecting funds as waste is generated, other liabilities associated with the management of waste generated, prior to the establishment of a financing system must also be addressed. In countries where a fund has been established and money is provided by the state budget, the organisation responsible for auditing government finances will also audit the financing system for long-term waste management. There are cases in which arrangements are made to independent auditors, who will also need to verify that the fund is being managed properly (e.g. Switzerland). In the countries, where the financial resources are maintained in reserve by the waste generators, professional auditors under contract with the nuclear power plant operators audit the reserve, in accordance with the rules for private enterprises.

2.4.5 Public Communication

It is widely recognised that transparency must be included in a radioactive waste management programme. Public attitudes, concerns and expectations about the safety of waste management activities (e.g. consequences of extended discharges or adequacy of long-term organisational arrangements and their ability to respond to problems) must be considered.

European countries with nuclear power are conducting public outreach programmes to facilitate public understanding and to build public confidence by various means (e.g. information packs, exhibitions, visits to nuclear facilities and meetings with programme staff). The public should also participate in the site evaluation and decision-making process.

There are two basic approaches in the European countries with nuclear power. Public representation can be included in the preparation of an environmental impact assessment, or participation in the waste management process at several different stages in the programme, as specified in legislation.

2.4.6 Decommissioning of Nuclear Facilities

Necessary infrastructure has been developed for the management of nuclear wastes, including decommissioning laws and regulations, funding to carry out the work and ‘know-how’ both in terms of experience/specific skills and special equipment. Early planning is important, due to the complexity of decommissioning projects.

The shift from operations to decommissioning requires a well-defined programme of work, similar to the methodologies used in the engineering industry. For a successful outcome, decommissioning must be treated as an engineering project with modern project management. A dedicated decommissioning organisation is also required. This new ‘mind-set’ often poses difficulties, as the nature of the forward is radically different, requiring both new technical skills and the need to control and manage budgets proactively, to achieve cost and time targets. Such changes create tensions as the order of priorities change. The decommissioning phase can lead to the loss of experienced and younger staff as they may face redundancy or significant changes in their jobs.

Decommissioning and dismantling of nuclear facilities are the responsibility of the operator and must be conducted under licence. A separate licence is often required for decommissioning.

The key points in decommissioning and dismantling (D&D) of nuclear facilities are:

1) The purpose of D&D is to allow the removal of some or all of the regulatory controls that apply to a nuclear site;
2) There is no unique or preferable approach to D&D of nuclear facilities;
3) Techniques for D&D are available and experience is being fed back to plant design and decommissioning plans;
4) Many nuclear facilities have been successfully decommissioned and dismantled, such as Germany, Belgium, France and the UK;
5) Current institutional arrangements for D&D (policy, legislation and standards) are sufficient for today’s needs;
6) Current systems for the protection of the safety of workers, the public and the environment are satisfactory for implementation and regulation of D&D;
7) Arrangements are in place for the funding of D&D, but evaluation of costs requires further attention; and
8) Local communities are increasingly demanding involvement in the planning for D&D.

In the majority of European countries with nuclear power, responsibility for the funding of D&D of nuclear facilities remains with the owner of the facility. The operator should maintain funds or financial guarantee for D&D, as required by national legislation or operating licences.

2.4.7 EU Strategies

The European Commission (EC) developed a "nuclear package" to reach a harmonised approach to nuclear safety and management of radioactive waste, including financing. This is based on the examination of national programmes for best practices and possible common strategies in the field of decommissioning and management of spent fuel and radioactive waste. The Commission's proposal is with the European Council, where approval has yet to be granted.

2.5 Public Acceptance

2.5.1 Euro barometer Results

Between February and June 2005, the European Commission carried out a survey of nuclear energy waste and public acceptance of nuclear power in the EU. The survey highlights some important aspects: for example, people who consider themselves well informed clearly show a better acceptance in all phases of nuclear waste. However, it should also be noted that only 25% of the citizens of the EU consider themselves well informed. The situation is especially negative, in terms of the opinions of women and young people aged between 15 and 24. The vast majority do not want further delays in setting up national strategies for high-level radioactive waste. They clearly want to be involved in the decision-making process and in the selection of the disposal sites. Harmonised strategies and management policies for radioactive waste are needed for the whole of the EU. Environmental non-governmental organisations (NGOs) are considered the most trustworthy sources of information, followed by independent scientists and the authorities. Far less trusted are national agencies responsible for nuclear waste. Across the EU, 37% of the people surveyed were in favour of nuclear energy, while 55% were against it.

2.5.2 Public Attitude Towards Nuclear Energy

Due to the increasing focus on climate change, particularly in the mass media, a shift towards a more positive perception of nuclear power seems to be taking place. Given the different approaches to nuclear power, European countries can be classified as follows:

A) Those using nuclear power;
B) Those using nuclear power, but with phase-out policies such as Germany, Sweden and Belgium;
C) Those not (yet) using nuclear power (e.g. Italy, Poland, Portugal and Serbia).

The perception of nuclear energy in Group A is not homogeneous. It ranges from very negative (Croatia, Russia) to very positive (Finland, Czech Republic, Romania and Bulgaria). Over the last 25 years in Finland, a positive perception of nuclear power has increased from only 25% in 1982 to 50% in 2005[7]. In the same period, the negative perception of nuclear power has dropped from almost 40% in 1982 to 20% in 2005. Thus, Finland has seen a complete shift in the opinion and perception of nuclear energy over the past 25 years. In the UK, there is also a trend towards a better public attitude towards nuclear energy. Polls conducted in December 2005, showed that 41% of those

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[7] Source: TNS Gallup Oy / Finnish Energy Industries.

interviewed were in favour of new NPPs, whereas a year earlier, the share was only 35%[8].

The share of nuclear power in the overall power production does not seem to play any role for public acceptance. In Spain and Switzerland, the main issues of concern are nuclear waste and its final disposal. At the same time, the political process for building new NPPs is extremely complicated. The very negative perception in Croatia, Serbia and Russia is related to Chernobyl and NGOs active in environmental issues; people do not feel they are taken seriously in their concerns by the government.

In Group B (phase-out countries), there is also a clear trend towards higher acceptance of existing nuclear power plants and understanding of the economical importance of their production. The high acceptance of nuclear energy has significantly risen in Sweden. In polls conducted in 2005, 83% of those interviewed either wanted to keep the country's reactor units or replace them with new ones. In the polls carried out in 2006, 85% wanted to keep the countries' ten reactors operational or build new ones[9]. In Germany, polls[10] show unclear results, 54% of those interviewed, believe that, despite the phase-out policy, nuclear energy will continue to play a role for a long time. On the other hand, only 22% want nuclear energy to secure the German electricity demand for the next 20 or 30 years.

In Group C countries, nuclear energy is viewed rather differently. Due to its attempt of reducing power production from coal, Poland is very positive. In Italy a shift in opinion has also taken place. In polls, 54% of those interviewed think that Italy should build its own NPPs instead of importing electricity produced in French NPPs[11]. Whilst 70% think that it does not make much sense for Italy not to have NPPs on it's own territory, while being surrounded by countries with NPPs.

2.5.3 Ongoing Debates and Discussions

Recent polls indicate that the steep rise in oil and energy prices in 2005 and the conflict between Russia and Ukraine about gas prices have had a significant impact on public opinion about energy.

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[8] Based on a sample of 2000 individuals.

[9] Conducted by the Swedish Analysis Group which is an expert group connected to KSU, Sweden's Nuclear Training and Safety Centre.

[10] Conducted in December 2005 by Allensbach, Institut für Demoskopie.

[11] Conducted in May 2005 by Istituto per gli Studi sulla Pubblica Opinione «Gli italiani e l'energia».

2.6 Governmental and Industrial Outlook for Nuclear Power

2.6.1 EU Policy

The EURATOM treaty governs the Members State's rights and responsibilities with respect to nuclear energy.

Although the treaty was conceived as a vehicle to assist the EU Member States in the development of this source of energy, it basically relies on the subsidiarity principle, leaving it to Member States to decide whether to use it. The UK Presidency of the EU in 2005, called for the establishment of a common energy policy, including the consideration of nuclear power as an alternative source. In 2006, the European Commission issued a Green Paper for consultation for a common energy strategy, including nuclear power.

2.6.2 Government Position in Key Countries and Future Plans

2.6.2.1 The EU-25

Amongst EU Member States with operating nuclear power plants, divergent political attitudes on the continued use of nuclear power has led to a variety of perspectives, regarding the future of nuclear energy.

At one end of the spectrum, nuclear countries such as Belgium, Germany, Spain and Sweden have abandoned any future development plans, adopting an array of measures to that effect.

- In Belgium and Germany, nuclear power phase-out laws have been adopted. While in Belgium, the newly-elected government has recently approved a study, the outcome of which might modify the phase-out law. In Germany, the construction of new nuclear plants is banned by law. Even the expected plant life extension approval, promised by the CDU Chancellor candidate in the 2005 election campaign, was dropped following the election.
- In Spain and Sweden, governments do not support nuclear power, with de-facto phase-out initiatives. The Spanish Socialist government has vowed to gradually replace the country's nuclear power plants with renewable energy sources, such as wind energy. The Swedish nuclear policy goes back to the referendum on nuclear power in 1980. The short-term objective to phase out nuclear power, however, has evolved into a long-term process. An initial step was taken when Barsebäck nuclear power plant was shut down, the first unit in 1999 and the second unit in 2005. It seems unlikely that any more reactors will be shut down in the near future. The Ministry of Sustainable Development states that the phasing out of the remaining reactors "must be made at a feasible pace and taking into consideration the need for electric power to maintain employment and welfare".

Other nuclear energy producing EU Member States without any clear plans for future nuclear development are Slovenia and the United Kingdom. Whilst existing plant operation, even long-term, is fully supported in Slovenia, no new plant construction is contemplated. In the UK, however, a recently announced energy review will look closely at the nuclear issue and the outcome of this review may favour new plant construction.

At the other end of the nuclear energy spectrum, countries such as Finland, France and the Czech Republic have included nuclear power for their long-term energy needs. In that respect, Finland is leading the EU's nuclear power resurgence with one new unit (OL3) under construction by TVO. This is boosted by a rather positive national climate strategy and from a neutral government policy, in support of nuclear.

In France, home of the world's largest nuclear electricity company, the present government fully supports nuclear energy. In a broad Energy Act voted by the French Parliament in July 2005, France has set amongst its priorities "to maintain the nuclear option open to 2020 with a new generation of reactors available by 2015 to allow the replacement of the current generation.” The government has launched a public inquiry for the construction of a new plant.

The Czech Republic government has also committed to a scenario that includes new nuclear power plants in its future supply of energy. Their State Energy policy approved in March 2004, not only assumes plant life extension for Dukovany NPP at least until 2030, but also two more 600 MWe NPPs to be added by 2025 and 2030 respectively.

Looking at EU Member States with no existing operating NPPs, only Poland has included nuclear power (2600 MWe) in its future energy strategy, but not before 2020.
In Italy and Portugal, there has been some recent debate on the nuclear option, but no real decisions by government or by private investors to build a nuclear power station have been taken. In Italy, the previous government had started to discuss the possibility of the nuclear option, and in addition, supported nuclear power investment by the Italian electric industry abroad (e.g. France, Slovakia). It is unlikely, however, that the outcome of the 1987 referendum, which practically led to the closure of all Italian NPPs, would be overturned. The current government is not in favour of using nuclear power in the short-term, but it plans to maintain Italy’s participation in foreign nuclear investment and research programmes.

2.6.2.2 Recent EU Members (Bulgaria, Croatia, Romania)

These countries have considerable NPP operating experience, for example, Croatia shares 50% of electricity from Krško NPP, located in Slovenia.
Both Bulgarian and Romanian governments are fully embracing the nuclear option for their country’s future energy needs, while Croatia has no plans for any NPP construction in the near future; due to negative public opinion on the grounds of environmental and safety concerns.

Romania is – with Finland – the only other European country with an ongoing NPP construction programme at their Cernavoda site. Unit 2 is scheduled for commercial operation in March 2007, to be followed by Unit 3 in 2012.
In Bulgaria, the government has decided to reopen the Belene project, with a deadline to complete the construction of two 1000 MWe PWR units by 2011. It considers nuclear generation crucial for the economy, as well as for the country’s energy independence.

2.6.2.3 Other European Countries (Switzerland, Russia, Ukraine, Serbia)

In Switzerland, power upgrades and life extension programmes have brought plant life expectancy to 50-60 years, but no plans exist for new construction, even though the new Atomic Energy law would allow it, subject to the time-consuming licensing process and referendum.

Russia and the Ukraine are amongst the major nuclear energy players outside the EU, with similar government approaches to their future energy needs. Both governments support the long-term strategy of nuclear power development and solid construction programmes. However, presently the Russian government is not investing in building new NPPs, so the only source for such investment is Rosenergoatom's profits from electricity sales, while the "Energy Strategy of Ukraine" foresees the development of nuclear energy to reach 52% of the country's electricity production.

Serbia, on the other hand, has no nuclear power plans as federal law prohibits NPP construction.

2.6.3 Industrial Preferences in Key Countries

Independently from government/official positions, Europe’s electricity producing companies and large industries seem to be overwhelmingly pro-nuclear.
Utilities and industry federations of nearly all Member and non-Member States are either strongly supporting their governments’ nuclear power programmes (France, Russia, Finland, Czech Republic, Bulgaria, Romania), or opposing phase-out laws and NPP construction bans (Belgium, Germany, Spain, Sweden). All specify price stability, security of supply and Kyoto emission commitments, as compelling reasons for continued or renewed nuclear energy production.

Most outspoken in this respect is EdF (France) who have re-stated their commitment to nuclear power, as the main technology for future base-load and to the renewal of their NPP fleet after 2020.
Despite the Swedish government´s phase-out policy, the industry intends to continue to operate the nuclear power plants, investing large amounts of money for safety modernisation, lifetime extensions and power upratings.

Countries of the Central/Eastern Europe region, facing rapidly growing electricity demands, have firmly included nuclear power plants in their economic and social development.

2.6.4 Obstacles to Further Development

With respect to obstacles to further development of nuclear energy in Europe, there is a clear distinction to be made between continued operation of the existing nuclear power plants, and new plant construction.

Public acceptance is a key factor in most countries, and in that regard, power uprates and plant life extensions are usually supported by the public. For new construction, however, political commitment is essential and positive public views. This is the case in Bulgaria, Czech Republic, Finland, France, Romania and Russia, countries which are or will be adding new NPPs for their future energy needs.

Sustained support for nuclear energy requires safety guarantees, energy security and economics. High investment costs, financing, and long construction times are often cited as major impediments for future development. The main issue, however, concerns the political aspect of waste management and disposal.

ANNEX 2-A

Description of External Costs (ExternE)

An external cost arises when social or economic activities have an impact on society not fully accounted for in producer costs, or compensated for through market price. For example, a power station that generates emissions of SO_2, causing damage to forests or human health, imposes an external cost. In this example, the environmental costs are external because, although they are real costs to society, the owner of the power station is not taking them into account when making decisions.

The ExternE project was a research project of the European Commission (EC). It was the first comprehensive attempt to use a consistent method, to evaluate the external costs associated with a range of different fuel cycles. The scope of the ExternE project was to evaluate the external costs, i.e., the major impacts of economic activities, both related to production and consumption. Up until now, evaluations of external costs have mainly been applied to energy-related activities such as fuel cycles, and activities related to transport.

The potential value of the ExternE project therefore lies in assessing external costs so those values can be included in the cost of electricity production. This is known as internalising the external cost. In the case of nuclear power, external costs include health and environmental damages from uranium mining, and further processing of uranium, as well as waste management for spent fuel.

The ExternE method has been applied in a large number of European and national studies to guide environmental, energy and transport policies. One of the first objectives of the ExternE programme was to make a comparative study of different technologies and fuel cycles for electricity production. (See attached Annex 2-B) It should be noted that these calculations sometimes include relatively large uncertainties; they reflect variations in national conditions, technologies, etc, as well as uncertainties in knowledge.

One approach to internalisation is to directly add an estimate of the external cost of producing electricity into electricity bills. This would imply, for example, adding between 4 and 7 cents per kWh to the current price of electricity production generated from coal. The corresponding external cost for nuclear power is estimated to be a lower factor of 10, about 0.4 cents per kWh. Another approach to internalisation would be to effect a reduction in pollution and hence a reduction in socio-environmental costs, by encouraging or subsidising cleaner technologies, or taxing pollution directly or indirectly through taxes on damaging fuels and technologies. Either approach results in external costs being considered as a factor in the total cost of electricity production. As shown in Table 1, the environmental benefit of nuclear power and renewables (wind, hydro) results in lower external costs, when compared to fossil fuels (coal, gas).

ANNEX 2-B
External costs for electricity production in Euro-cents/kWh

	Coal/ lignite	**Peat**	**Oil**	**Gas**	**Nuclear**	**Biomass**	**Hydro**	**PV**	**Wind**
Austria	-	-	-	1-3	-	2-3	0.1	-	-
Belgium	4-15	-	-	1-2	0.5	-	-	0.6	0.05
Denmark	4-7	-	-	2-3	-	1	-	-	0.1
Germany	3-6	-	5-8	1-2	0.2	3	-	0.6	0.05
Finland	2-4	2-5	-	-	-	1	-	-	-
France	7-10	-	8-11	2-4	0.3	1	1	-	-
Greece	5-8	-	3-5	1	-	0-0.8	1	-	0.25
Ireland	6-8	3-4	-	-	-	-	-	-	-
Italy	-	-	3-6	2-3	-	-	0.3	-	-
Netherlands	3-4	-	-	1-2	0.7	0.5	-	-	-
Norway	-	-	-	1-2	-	0.2	0.2	-	0-0.25
Portugal	4-7	-	-	1-2	-	1-2	0.03	-	-
Spain	5-8	-	-	1-2	-	3-5	-	-	0.2
Sweden	2-4	-	-	-	-	0.3	0-0.7	-	-
UK	4-7	-	3-5	1-2	0.25	1	-	-	0.15
Average	**4.1 - 7.3**	**2.5 - 4.5**	**4.4 - 7**	**1.3 - 2.3**	**0.4**	**1.2 - 1.6**	**0.4 - 0.5**	**0.6**[12]	**0.1 - 0.2**[1]

Source: ExternE Study by the European Commission, 2001

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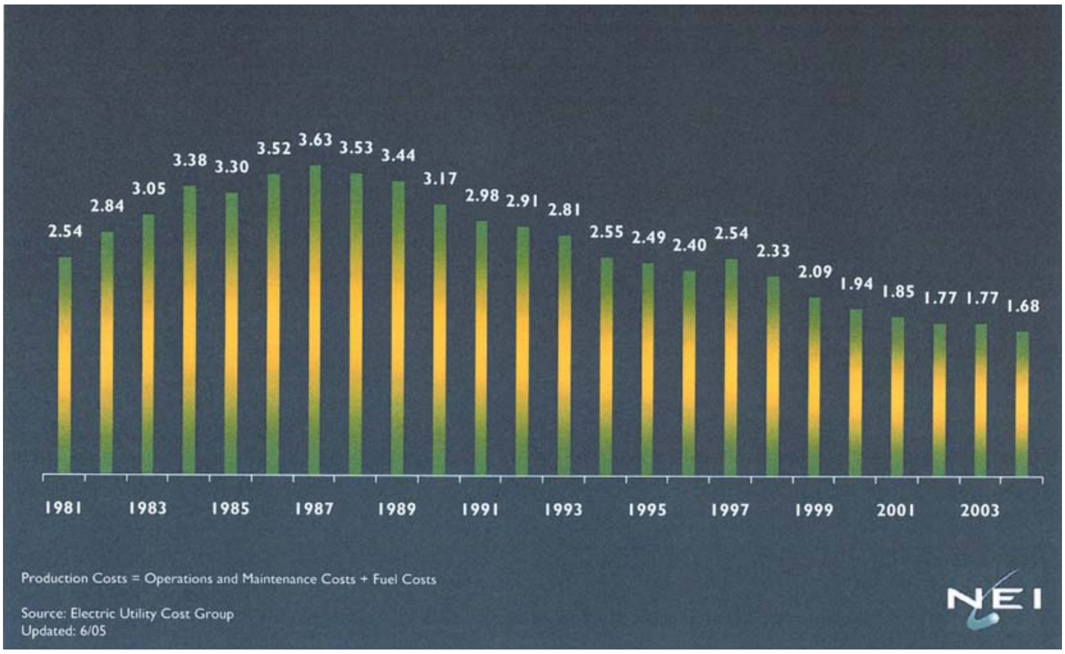
[12] Note by the WEC Study Group: when the total cycle external costs of PV and wind are considered, including the reduced efficiency of fossil plants needed to complement wind generation; these sources are comparable to gas.

ANNEX 2-C
US Nuclear Industry Production Costs 1981-2004 (Averages in 2004 cents per kilowatt-hour)

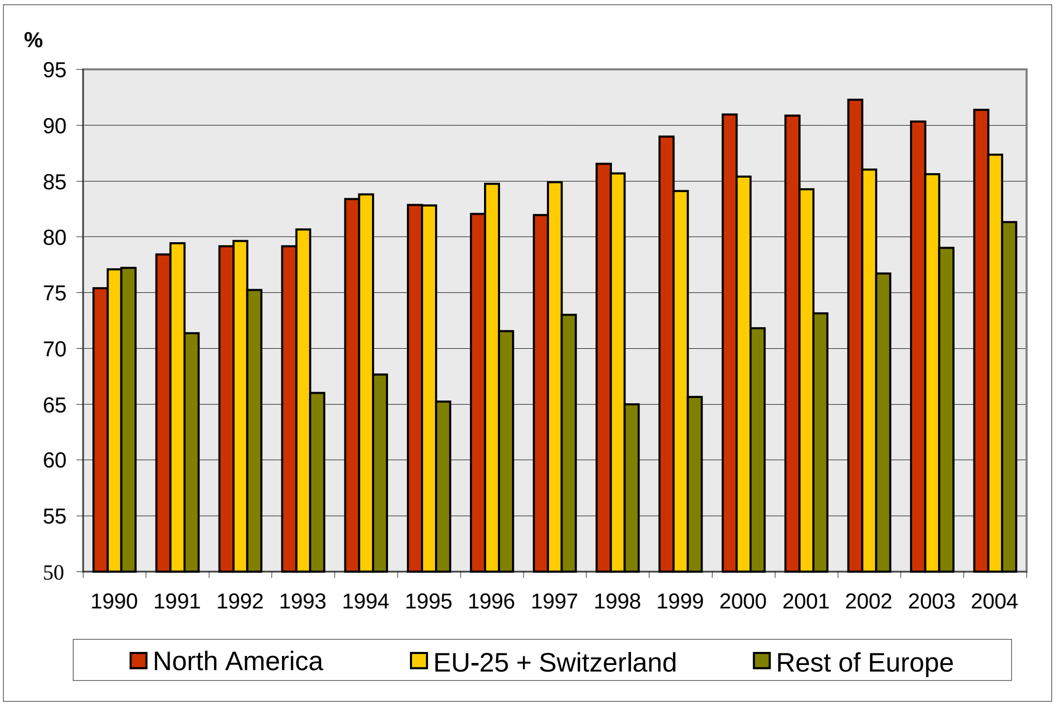


Production Costs = Operations and Maintenance Costs + Fuel Costs

Source: Electric Utility Cost Group
Updated: 6/05

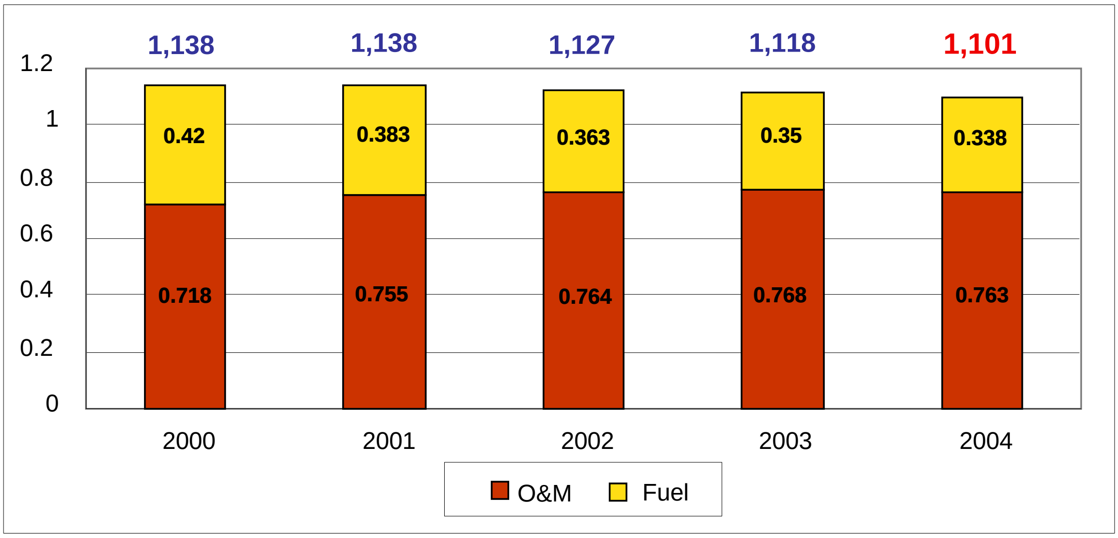
Source: Nuclear Energy Institute, EUCG – Updated 6/05

ANNEX 2-D
Comparison of Availability Factors between North America and Europe



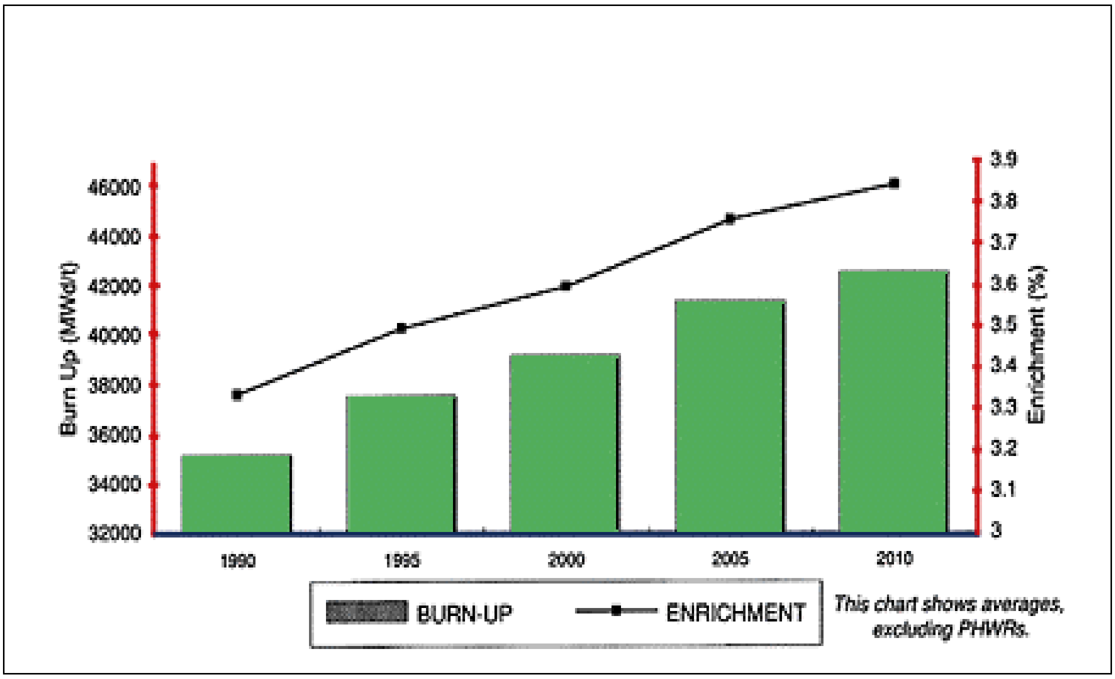
Source: "Nuclear Energy Trends", J.Mandula, IAEA, Vienna, Austria

ANNEX 2-E
Nuclear Production Cost in Spain



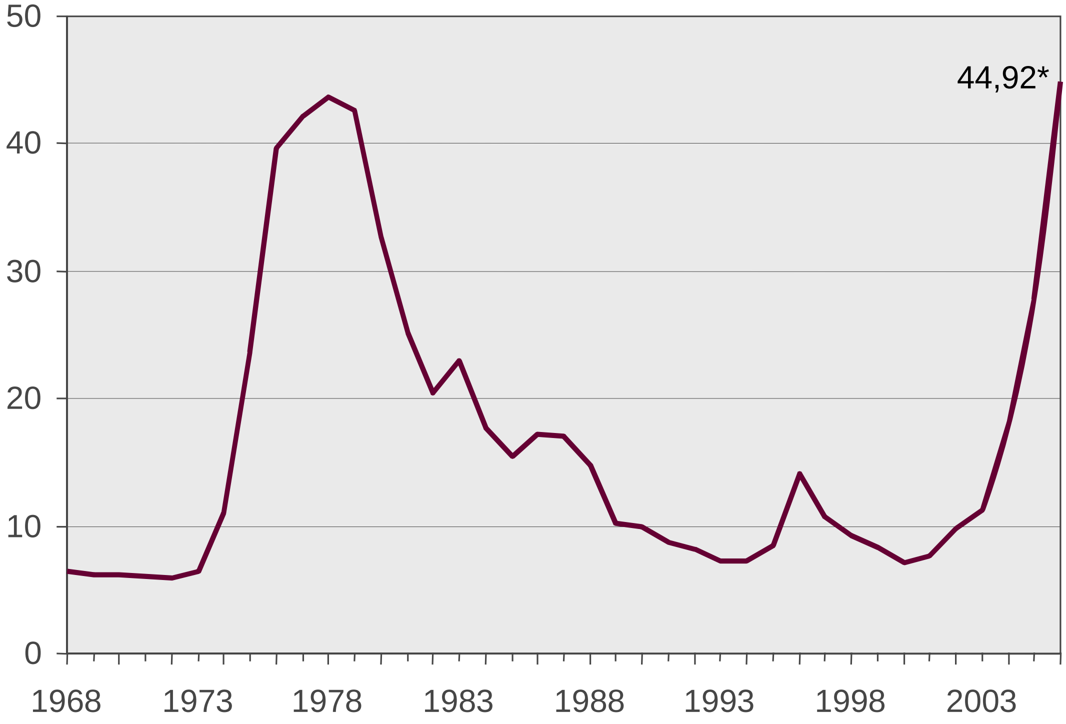
Source: UNSEA, Data in €/kWh (2004)

ANNEX 2-F
Worldwide Trend of Increasing Fuel Utilisation
(Burn-up measured in MW/days per metric tonne)



Source: "The Long-Term Sustainability of Nuclear Energy", WNA Submission to UK Energy Review

ANNEX 2-G
Uranium Price Development (US$/lb)



[*] Average price for the period 1 January through 31 October 2006

Source: NUKEM GmbH, October 2006

CHAPTER 3: DEVELOPMENT OF NEW NUCLEAR POWER PLANTS WITH EXISTING TECHNOLOGIES (2010/2030)

In Chapter 2, it was shown that nuclear power plants (NPPs) currently generate a significant share of European electricity. The purpose of this chapter is to examine the conditions, under which new nuclear plants are likely to be decided and built in the future. For the decades until 2030, we can begin with the following data:

- Many power plants operating in base-load, mainly coal-fired and nuclear are approaching their end of life and must be replaced, at an increasing rate from 2010 onwards. Moreover, electricity demand is expected to grow at a rate of 1.5 to 2.0% per year and will require more capacity.
- The “Large Combustion Plant”, a European Union Directive imposing stringent SO_2 and NO_X emissions limits on existing power plants will accelerate the decommissioning of old coal power plants.
- The renewal of generating capacities should be an opportunity to select fuels and technologies in consonance in line with overall European priorities, such as energy security, competitive economics and climate change mitigation. Until recently, combined cycle gas power plants were seen as the only solution to new capacity needs. Recent events have shown that their economic competitiveness might be lower than expected and that extensive use of natural gas raises energy security concerns.
- Available technologies are known as Generation three reactors; designs have incorporated the latest safety requirements. They have already been licensed in a European or North American country or are nearly licensed.

The first condition to be examined is the need for new generating capacity in Europe, to compensate for retirements and to follow demand growth.

According to estimates by the International Energy Agency (IEA) in “World Energy Outlook”, (WEO, 2004), the total generating capacity in service would increase by 480 GW from 2010 to 2030, an average growth of 1.5% per year. The replacement of retiring old capacities would also be included; IEA estimates that more than 1,000 GW must be installed between 2000 and 2030.

Region	Capacity in 2002 GW	Capacity in 2010 GW	Capacity in 2030 GW	AGR 2002-2030 %/year
OECD Europe*	743	850	1 159	1.5
Transition economies	411	445	617	1.5
Total Europe*	1 154	1 295	1 776	1.5

*including Turkey, according to IEA geographical conventions

Source: IEA/WEO 2004

3.1 NPP Technologies Available on the Market

The technologies to be considered for investment over the period 2010-2030 were selected, according to the following considerations:

3.1.1 General Performance Objectives

For all proposed technologies on the market, safety and cost performance are set at a high-level, which would probably be required by the majority of potential European buyers:

- Design lifetime: 40 to 60 years;
- Availability: significantly higher than 90%;
- Core management and refuelling: capable of 12 to 24 month cycles;
- Low core damage frequency ($<10^{-6}$) and lower probability of large off-site releases ($<10^{-7}$);
- Very low occupational radiation exposure; and
- Short (or very short) construction schedules.

The following improvements in safety, reliability and operability are targeted:

- Simplification of systems engineering;
- Significant reduction in the effects of common cause faults;
- Lower susceptibility to human error;
- Lower cost and effort for inspection and maintenance; and
- Improved accident management and minimised external consequences.

Moreover, reference power plant specifications have been elaborated by several European electricity producers (12 companies or association of companies: British

Energy plc, Electricité de France, Fortum, Iberdrola, NRG, Rosenergoatom, ENEL, Swissnuclear, Tractebel, TVO, Vattenfall, VGB Powertech) in the European Utility Requirements (EUR) document. The primary objective is to suggest a common reference for the development of next generation, light water reactor (LWR) NP plants, to allow the emergence of several standardised LWR designs that could be proposed throughout Europe without major design changes, adapted to the future needs of European utilities. This is expected to improve nuclear energy competitiveness and public acceptance in a more open European electricity market..

Other uses for the EUR document include bid specification and as a tool for the harmonisation of the rules for the European unified electricity market, such as nuclear safety and connection to the high voltage grid. The document was used as a basis for the bid specification of the fifth Finnish nuclear unit in 2002-2003. The document refers to 5 reactor designs:

Boiling water technology,

- ABWR, 1400 MWe, by General Electric,
- SWR, 100 MWe, by Framatome ANP,

Pressurised water technology,

- EPR, 1500 MWe, by Framatome ANP,
- AP 1000, 1115 MWe, by Westinghouse,
- VVER V-392, 1000 MWe, by AEP Moscow.

There is great potential for cost reduction in design standardisation, as experienced in France, Germany and Russia. It should be possible to build a given design identically over a wide geographical area, over a long period of time. The goal is to achieve a catalogue of standardised models to meet the requirements of potential customers and regulators.

3.1.2 Unit Capacity

Three factors are driving decisions in favour of large unit capacity:

- The size effect reduces the construction costs per unit of power;
- For a given technology, the number of employees needed to operate a NPP is almost independent of the size of the plant;
- In many cases, there is a scarcity of available sites on which to build new NPPs.

In the majority of European countries, electricity consumption is high enough to allow the operation of large-size nuclear plants, facilitated by sufficient interconnections with neighbouring countries. In most European countries, the grid is sufficiently interconnected to sustain up to a 1600 MWe unit loss, in case of an unplanned shutdown.

In many European countries, only ‘large-size’ (i.e., 1000 MWe or greater) NPP can successfully compete. This definition of ‘large-size’ is more restrictive than the IAEA definition, but seems better suited for European characteristics. All vendors can provide 'large-size' designs except the Atomic Energy of Canada Limited (AECL), which is, however, actively developing the ACR-1000 (1000 MWe).

Some countries or some utilities may still prefer smaller reactor sizes, largely for financial reasons. Small PWRs have been designed with this goal and are under development (e.g., the IRIS, 300 MWe by Westinghouse).

3.1.3 List of Reactors under Consideration in this Chapter

- ABWR, ESBWR, both developed by General Electric, and SWR 1000, developed by Framatome ANP. These three models belong to the boiling water reactor (BWR) family and are large-size reactors as previously defined.
- European pressurised water reactor (EPR, developed by Framatome, ANP; AP-1000, developed by Westinghouse; and V-392 (VVER-1000), developed by Gidropress. These reactors belong to the pressurised water reactor (PWR) family and are also large-size reactors.
- Candu-6, ACR 700 (developed by AECL) are heavy-water reactors, these models are close to 700 MWe in size.

The models - ABWR, EPR and SWR 1000 have been examined and validated by the European utilities in the framework of the EUR document. This process is ongoing for AP-1000 and for V-392.

A short description of each reactor is given in Annex 3-A. More details can be found in IAEA-TECDOC-1391, "Status of Advanced Light Water Reactor Designs", May 2004, published by the International Atomic Energy Agency (IAEA).

3.1.4 High Temperature Reactors (HTR)

Innovative high temperature reactor designs like the Pebble Bed Modular Reactor PBMR (South African Project) and the Gas Turbine Modular High Temperature Reactor GT-MHR (an international project involving US, French and Russian teams) use helium as a coolant. Temperatures as high as 950°C are made possible by new structural materials performance. These are clearly small size reactors with the potential to provide nuclear power for applications, besides grid-connected power generation such as:

- Applications where high temperature heat is required or at least favourable (process industries, desalination, hydrogen production);
- Combined heat and power supply;
- Cases in which the total unit capacity needed would be 600 MW thermal at most, supplied by modular reactors.

In Europe, opportunities may arise when industrial platforms (refineries, ammonia production, steel production, etc) use new concepts for on-site energy supply. However, the economics of such small reactors still need improvement. Time is needed for further reactor development, for cost optimisation and for industrial demand to develop. Attractive cases for HTRs in Europe are likely to remain rare until 2030. However, it is hoped that by launching a few projects under attractive conditions, it would support further development and cooperative projects. The vision Europe develops about hydrogen use in the future will be a key consideration in large-scale nuclear power development: hydrogen fuel cells for transportation, synthesis of new liquid fuels by hydrogenation of high carbon content materials (coal, tars, residues, etc)? Presently, nuclear energy contributes to 6% of the world's primary energy supply. If new uses emerge, the contribution beyond 2030 could rise to 20% of the world supply (See Chapter 4).

3.2 Nuclear Fuel Cycle

Nuclear power development in Europe implies that fuel procurement can be ensured for a long time at a reasonable cost and that material flow does not raise overwhelming problems of transport, treatment and storage.

- ***Orders of Magnitude***

The consumption of nuclear fuel in Europe will evolve as a function of installed capacity. For example, the total capacity is assumed to remain nearly constant from 172 GWe in 2005 to 178 GWe in 2020, in the "reference scenario" selected by World Nuclear Association (WNA, 2005 report on "Global Nuclear Fuel Market"). This scenario takes into account, plant life extension in most countries, current decisions on phasing-out plants in several countries such as Belgium and Germany and capacity increases in others (Russia, Ukraine). In the "upper scenario", phasing-out policies are cancelled and renewal is more bullish (e.g., in the UK); the outcome in 2020 is 12% more nuclear capacity, than in the "reference scenario".

- ***WNA projections***

2005	**Net Capacity, GW**	**Uranium U nat, t**	**Enrichment 1000 SWU***
West & Central Europe	134	22226	14641
East & South-East Europe	38	5965	7852
TOTAL EUROPE	**172**	**28191**	**22493**
World	367	64548	45093
2020 Lower Scenario			
West & Central Europe	102	17879	12700
East & South-East Europe	39	6195	8276
TOTAL EUROPE	**141**	**24074**	**20976**
World	364	66557	48136
2020 Reference Scenario			
West & Central Europe	131	24851	17398
East & South-East Europe	47	7308	9704
TOTAL EUROPE	**178**	**32159**	**27102**
World	446	84740	60985
2020 Upper Scenario			
West & Central Europe	144	27331	18989
East & South-East Europe	54	9513	12526
TOTAL EUROPE	**198**	**36844**	**31515**
World	518	102869	75186

* SWU = Separation Work Unit, measures enrichment services as a function of treated volumes (feed, enriched product and depleted product) and concentrations in isotope 235U.

Source: WNA 2005 report "Global Nuclear Fuel Market"

It is worth noting, that the projected quantities of uranium consumed and SWUs required are increasing more rapidly than installed capacity, mainly because of progress on power plant load factors. The trend towards higher burn-up (i.e., the energy extracted from one fuel element) reduces the number of fuel elements consumed per kWh generated.

In all scenarios, the European share of global nuclear fuel consumption and associated operations (uranium mining, enrichment services and fuel fabrication) is expected to decrease.

- ***Natural Uranium Supply***

Europe will remain strongly dependent on external sources of uranium:

- It consumes more than 28,000 t per year;
- It produces less than 5,000 t per year (Russia, Czech Republic).

Moreover, the current global rate of consumption (65,000 t/year) widely exceeded the world mining production of 36,000 t/year in 2004. The rest of the supply is drawn from existing military and civilian stockpiles: weapons grade uranium from dismantled weapons, natural uranium as U_3O_8 yellow cake, depleted uranium recycled after re-enrichment, and reprocessed uranium from spent-fuel reprocessing. Spent-fuel reprocessing, also recovers plutonium which is then recycled as MOX fuel in LWRs. When recycling and existing stockpiles are no longer sufficient, new mines must be opened.

The latest OECD/NEA-IAEA report (“Red Book”) on uranium resources, released in June 2006, with the following updated figures, assuming a maximum price of US$130 /kgU:

- Total volume of identified resources (so-called “reasonably assured resources (RAR) plus estimated additional reserves”) is 4.75 MtU;
- Undiscovered resources equal to 10.0 MtU: 2.9 MtU of which are reported without reference to production cost;
- Total identified and undiscovered resources are thus 14.75 MtU; and
- Unconventional resources such as uranium in phosphates extend the resource base by 15-25 Mt.

In 2020, in the Upper Scenario from WNA, world uranium consumption would reach about 100,000 t/y. Starting a new NPP at that time would require ensuring feedstock for 60 years, relying on world resources for at least 6 million tons. Sufficient supplies are anticipated to be available as the result of new expenditures in exploration and mining, triggered by higher prices of uranium.

The uranium market is subject to the usual commodity cycles, in which rising prices signal the need for new investments. International uranium prices were as low as US$20/kg (= US$8 per pound of yellow cake, U_3O_8) in the beginning of this decade, before climbing to more than US$100/kg (US$40 per pound of U_3O_8) in 2006. In the near future, the start-up of large low-cost mines (e.g., Cigar Lake in Canada and Olympic Dam extension in Australia) will most probably drive prices downward.

It is worth mentioning, that two leading world uranium companies are based in Europe, Rio Tinto (UK) and AREVA NC (France), second and third world producers behind Cameco, the Canadian company. They operate uranium mines mainly in Canada, Australia, Niger and Namibia.

- ***Conversion***

Conversion of uranium oxide to UF6 is required before enrichment. The global demand for conversion will increase with natural uranium demand. A major share of world capacities operate in Europe (France, Russia, and the UK) and the increase in production should not pose problems in the future.

- ***Enrichment***

Europe holds a major share of world enrichment capacity and will continue to export these services. It consumes 20 to 23 million separative work units (MSWU) per year, but has an installed capacity of more than 36 MSWU.

Ultracentrifugation is becoming the reference enrichment technology and European technology is dominant in this area. Recently, it was decided to build a centrifugation plant to replace the Eurodif gas diffusion plant at Tricastin in France.

Location	Nameplate capacity (2005)
Eurodif (in France)	10,800
Urenco (in Germany, Netherlands, UK)	7,300
Rosatom (in Russia)	20,000
TOTAL Europe	**38,100**
World	51,750

Source: WNA 2005 report "Global Nuclear Fuel Market"

The current trend towards higher uranium prices has led customers to increase the efficiency of uranium recovery during enrichment, lowering the concentrations of U_{235} in the outgoing depleted stream, thereby consuming more SWU (enrichment units). The quantity of uranium imported is thus decreased, due to the increased utilisation of domestic facilities.

- ***Fuel fabrication***

Europe is also self-sufficient in fuel fabrication, and is likely to remain so, as long as European nuclear power plants are supplied with European technology, (i.e., by European reactor and fuel vendors). The total European consumption of heavy metal (uranium and plutonium) in light water reactor fuel assemblies amounts to some 3,000 t/year (world consumption being about 7,500 t/year). Mixed oxide of uranium and plutonium (MO_X) fuel for light water reactors is also fabricated in two plants.

List of European fuel manufacture plants:

Plant	Country	Capacity (UO2 t/year)	Fuel Designs	Company
Dessel	Belgium	500	BWR, PWR	Areva
Lingen	Germany	650	BWR, PWR	Areva
Marcoule	France	145	MOX for LWR	Areva
Novossibirsk	Russia	1,535	VVER, RBMK	TVEL
Romans	France	1,200	BWR, PWR	Areva
Sellafield	UK	50	MOX for LWR	BNF
Springfields	UK	250	AGR	Westinghouse
Jusbado	Spain	400	BWR, PWR	Enusa
Vasteras	Sweden	400	BWR, PWR	Westinghouse
	Romania		PHWR	

- ***Recycling Capacities***

Fuel procurement will be partly accomplished by recycling nuclear materials. Industrial facilities are on line for spent-fuel reprocessing and MOX fuel fabrication, and these capacities can be expanded.

- Spent-fuel reprocessing produces plutonium and reprocessed uranium, both to be recycled in power plants. The total European reprocessing capacity of approximately 3000 t/year can obviate the need for some 9000 t/year of natural uranium. However, it is not used at full capacity and the projected rate of plutonium and uranium recycling is expected to save 2,000 t/year.

- Stockpiles from weapons dismantling (Russian highly enriched uranium (HEU) and Pu, British Pu) could supply the equivalent of up to 1,000 t/year of natural uranium.

- Re-enrichment of depleted uranium in centrifuges generates the equivalent of 3,000 to 5,000 t/year natural uranium.

The effective level of recycling depends on national policies and on the number of reactors licensed for non-classical fuel elements. It also depends on natural uranium prices.

- ***Conclusion***

European nuclear technology and industry provide robust and sufficient capacity for nuclear fuel procurement. The weak step is uranium mining, since domestic resources are scarce. All other operations are mastered on the continent: conversion, enrichment, uranium fuel and MOX fuel fabrication and reprocessing.

The main question in the long-run will be uranium procurement and prices. To secure nuclear fuel procurement in Europe, significant investments could be made, both in uranium exploration and extraction abroad and in domestic material recycling.

3.3 Radwaste and decommissioning

In the context of extended nuclear generation in Europe, the key regulatory and policy conditions for waste management appear to be the following:

Each country is responsible for its own waste, including final disposal. In the future, joint repositories for some smaller countries could be possible for higher overall cost efficiency, but currently, the populations are unwilling to envisage it. In France, the law enacted in June 2006, absolutely forbids the disposal of imported radioactive waste.

As soon as possible, operational repositories for the final disposal of low-level waste and short-lived intermediate level waste should become standard practice, with relatively simple designs and operations in all countries involved. They should have a corresponding simplified approval process, involving the local communities, commensurate with the low levels of hazard posed by these wastes. Such repositories have operated for many years in several countries without major challenges: Czech Republic, Finland, France, Germany, Russia, Slovakia, Spain, Sweden and the UK.

For all types of waste, a regulatory framework should be formed to define the objectives, principles, responsibilities, funding processes and implementation schedules. The first prerequisite for public trust is a demonstration that public authorities carefully handle the problem. Transparency is required in the decision process and in the funding system.

For high-level waste (HLW) or spent fuel, national programmes should be launched to demonstrate safe technologies for final disposal in different geological environments and to select suitable sites for repositories. International consensus about the safety of geological disposal and international cooperation form a good basis for the development of disposal technologies. When the search for a site is initiated, public involvement is necessary. Success requires public and political confidence, and real benefits to the local communities hosting repositories.

In all countries, finding a site for the geological disposal of HLW or for spent fuel has proved difficult not for technical reasons, but for political reasons. Once a suitable site has been found displaying favourable geological properties and having the support of the local population, the confidence building process can take several years.

The long period required to decide upon and implement final waste and spent fuel disposal measures does not raise safety questions about interim solutions, since spent-fuel elements and vitrified high level waste can be safely stored for several decades either in dedicated ponds (e.g., in Sweden) in ventilated dry storage wells (e.g., in France), or simply confined in separate high performance storage casks, when quantities are more limited (e.g., the Netherlands).

Even when effectively selected and operated in several countries, it is preferable to minimise the number and the size of required repositories. For this reason, the choice of spent-fuel management technologies becomes significant, especially for countries with a large number of nuclear plants, since the volumes of HLW may be different between direct spent-fuel disposal and spent-fuel reprocessing options. The final packaged volume would be about 2 m^3 per ton of uranium in the case of direct disposal (assuming a Scandinavian package design in a copper cask) and 0.5 m^3 per ton in the case of reprocessing (assuming French technology, i.e., vitrified fission products and compacted fuel structure and process waste).

Even though no geological disposal site is operating, the principles now seem well established. Consensus among experts has been increasing for a long time. European countries are taking steps forward, as shown by several recent declarations and decisions:

- Finnish Parliament decision in 2001, for a repository near Olkiluoto power plant, to be commissioned by 2020.
- French Waste Law enacted in June 2006, which requires a national waste plan including deep geological disposal of some waste categories and defines financing rules for this plan. The objective is to be ready in 2015, to apply for authorisation of a geological repository, which could begin to operate in 2025. The authorisation would be based on the results of the underground research laboratory on the same site.
- On 31 July 2006, in the UK, the national advisory committee, Committee on Radioactive Waste Management (CORWM) concluded that in the current knowledge of best available approaches; geological disposal is the best option for the long-term management of the UK’s high level waste (HLW).

For funding such long-term expenses such as plant dismantling and high level waste and spent fuel disposal, sufficient money should be put aside each year, either as added internal dedicated assets on the company balance sheet or as annual payments to a dedicated external fund. Such funding must be set up from the beginning of life of the plant, so that long-term capitalisation is effective and can even include a margin for cost uncertainties, without excessive impact on the total lifecycle cost.

The non-discounted costs of waste management and decommissioning are typically around 10% of nuclear electricity production costs; since most of the expenses occur long after electricity has been generated, their effective weight in levelised lifecycle cost is much lower, through time discounting. In most countries, sufficient funds are set-aside during the operating lifetime of the power plants to cover the future costs of waste management and decommissioning.

In 2006, estimated total nuclear waste management costs (including future disposal) and current level of funding were announced in Spain (13 billion Euros (B€) for the period 1985 to 2070) and Switzerland (11.9 billion Francs Suisse, i.e., 7.5 B€ based on 40 years’ nuclear power operation). In Sweden, the estimated total waste management cost is also periodically updated and published by the waste management company, SKB. In France, investment and operating costs of a geological repository were estimated between 13.5 and 16.5 B€ (non-discounted) for a repository containing all high level wastes (HLW) and long-life intermediate level wastes. These wastes have been or will be generated by existing French nuclear power plants, assuming generation of 400 TWh each year during forty years.

Funding policies vary from one country to the other: either an external strategy where the management of funds is separate from the accounts of the nuclear operator, or an internal strategy where the company can select the destination of its own provisions for future expenses. Examples are given in the table below. The first option provides transparency and more security in the future availability of funds, while the second option is consistent with principles of assigning full technical and financial responsibility to the operator, permitting more efficient use of funds. Both strategies are consistent with a principal of assigning full technical and financial responsibility to the operator.

Nuclear Waste and Dismantling Funding Policies in Europe

Country	Funding policy	Operators affected	Operator Ownership
France	Internal	EdF	Government
Germany	Internal	E.ON, RWE	Private
Czech Republic	External/Internal	CEZ	Government
Slovakia	External	Slovenske elektrarne AS	Government
Spain	External	Iberdrola, Union Fenosa, Endesa, Hidrocantabrico	Government
UK	External	British Energy	Private

Source: Company reports, Nuclear Energy Agency

3.4 Economics of New Nuclear Power Plants

The profitability of a new power plant can be expressed as its net present value, adding all discounted annual revenues from electricity sales and subtracting all discounted annual expenses over the lifecycle of the plant. The average sales price required to make the project profitable comes down to the estimated lifecycle levelised generation cost.

Expenses to be included in the generation cost:

- Initial investment for licensing, construction and start-up;
- Annual operating and maintenance (O&M) costs, including overhead and taxes;
- Annual fuel procurement and management, including final waste disposal; and
- End-of-life decommissioning.

Over the last few years, a number of studies (see references) have examined the cost of nuclear power compared with other technologies like gas-fired combined cycle turbines (CCGT), coal-fired power plants and windmills. They highlight the following cost structure of the different generating technologies:

	Nuclear	**Gas CCGT**	**Coal**	**Wind**
Investment*	50-60%	15-20%	40-50%	80%-85%
O&M	30-35%	5-10%	15-25%	10-15%
Fuel	15-20%	70-80%	35-40%	0%

* Including decommissioning

Examining the main components of costs set out in the table above (i.e., construction, fuel, operation and maintenance, together with decommissioning) it suggests that if utilities decide to build new NPPs, we are likely to see:

- Fleets of near identical plants, to gain benefits from series and standardisation;
- Large reactors favoured over smaller reactors and used for base load (as O&M costs are not closely linked to plant size or level of generation);
- Plant availability of more than 90% (based on international benchmarks);
- Plants funding their decommissioning by provisions over their operating lifetime;
- NPPs used as a hedge against fossil fuel prices as part of a diverse energy mix.

Investment costs consist of the overnight cost and interest during construction (IDC). Depending on construction time and interest rates, the capital cost is generally 20-30% higher than the overnight cost (OVN), due to the interest during construction. ‘First-of-a-kind’ (FOAK) specific costs can have a significant impact on capital costs, sometimes estimated to be as high as 35%[13].

The overnight cost (OVN) is the sum of all expenses that would occur if the entire project could be completed in a single day. All of these costs depend significantly on different technical specifications (location of the plant, heat balance, etc.) They include:

- Owner’s costs (site preparation costs and regulatory compliance costs);
- Engineering, procurement and construction costs (preliminary studies, engineering, purchase of equipment, erection, civil works, etc.), concerning both the nuclear and the turbine island; and
- Contingencies.

The IDC costs cover financing and the timing of expenditures.

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[13] University of Chicago, The Economic Future of Nuclear Power, 2004, USA

FOAK costs are an important issue. Allocation of costs among the first units built will affect first unit overnight costs, the effect depending on the vendors' ability to sell multiple reactors. The benefits of the series effect are best realised when the time gap between projects supplied by the same vendor are fairly reasonable (6 to 24 months). The impact of series benefits on both construction cost and build time suggest, it is most cost effective for a utility to build several plants of the same design.

3.4.1 Proposed Best Estimates of OVN Construction Costs and Time Length in Europe

For a given design and unit capacity, construction costs can vary over a broad range, according to the various parameters:

- Country and site characteristics, including seismic and cooling aspects;
- Costs of manpower and materials;
- Project management and subcontracting scheme;
- Number of units of the same type already built and operated;
- Requirements for local supply and local skills;
- Licensing process (one or two steps);
- Political environment impact (delays in granting a construction permit, interruptions during construction).

We consider the total "overnight construction cost" as when a plant supplier can ensure engineering, procurement, construction and contingencies mainly on their own, but not the owner's costs of site preparation, authorisation procedures and pre-commissioning tests.

3.4.1.A The OECD/NEA-IEA Update (2005), estimates OVN construction costs in several European countries for future new capacity, as shown in the following table.

Overnight Construction Costs in Europe, for Commissioning around 2010

Country	Reactor Type	Net capacity in MWe	Million Euros (2003)	€/kWe
Finland	PWR	1500	2485	**1650**
France*	PWR	1590	2163	**1360**
Netherlands	PWR	1600	3000	**1870**
Romania	PHWR	665	1049	**1570**
Slovakia	VVER	894	1365	**1520**
Switzerland	BWR	1600	2633	**1640**

** for a series of 10 EPR*

Source: OECD/NEA-IEA 2005, Table 3.12, based on 2003 Euros

3.4.1.1 Estimates are Available for Ongoing Projects in Europe

1) Pressurised Water Reactor (PWR)

Olkiluoto 3 in Finland: to be commissioned in 2010 with a total investment of 3 B€, declared by the TVO company without details on the exact content. This is consistent with the OVN cost value of 1650 €/kWe (Base 2003 €) declared by Finland in the Organisation for Economic Cooperation & Development (OECD) report .

Flamanville 3 in France: to be commissioned in 2012, with an OVN of 3.3 B€, or 2025 €/kWe (Base 2005 €) declared by EdF in May 2006.

Both projects can be considered as FOAK since they are based on the European pressurised water reactor (EPR) design, with no previous EPR experience available. Flamanville 3 costs also include EPR development costs.

2) Pressurised Heavy Water Reactor (PHWR)

Cernavoda 2 (655 MWe) in Romania: for commissioning in 2007. The cost of completing the project, since it was restarted in March 2003, is about 777 million Euros (civil works already completed).

3) Light Water Reactor – Russian (VVER)

In Russia, Rostov 2 is to be completed in 2009, for a cost of 30 billion roubles (1120US$/kWe).

Kalinin 4 is to be commissioned in 2011, with the completion cost of 48 billion roubles (1810 US$/kWe).

3.4.1.C Best Estimates for Future Generation 3 Projects in Europe

The OVN cost of future Generation 3 projects should be lower than the costs recently announced for the two first EPRs. With respect to current FOAK projects and according to past experience, the cost of construction of new nuclear power plants will benefit from several factors:

- Learning effect;
- Series effect; and
- Twin units on the same site, in some cases.

These effects are discussed in the report by the University of Chicago “The Economic Future of Nuclear” August 2004. Moreover, the international competition presently prevailing among at least five vendors is a powerful factor in driving prices downward with benefits.

According to the vendors’, the OVN cost is likely to stay in the 1300—1800 €/kWe range (in Euros, 2005). Even lower costs may be realised, when the full benefits from series and site effects can be achieved. For example, the OVN cost of 1360 €/kWe indicated by France in the OECD report [See table 3.4.1.A] was estimated in 2003, based on a programme series of 10 EPR. Most of the series effect would be reached with 6 reactors, two per site. More precise estimates would be elaborated in a more specific context.

3.4.1.2 *Construction Time*

The time required to complete a new nuclear plant depends on conditions, and should be shorter for n^th^ of a kind than for the first of a kind.

It is relevant to distinguish two periods:

I. From first concrete poured to first fuel load into the reactor, this period is predominantly managed by the reactor supplier,

II. From fuel load to commissioning and connection to the grid, again mostly managed by the owner/operator.

The first period may last as long as 60 months for a FOAK plant. For subsequent plants, the reactor suppliers indicate a range of 36 to 50 months, depending on specific design features, project management and manufacturing schemes and interactions with safety authorities.

The second period usually requires around six months.

Except for FOAK, total construction time ranges from 3.5 to 5 years. Some components are pre-ordered before the first concrete is poured to minimise total time toward commissioning. For the owner, this means the decision would be taken earlier, but with limited risk in most cases.

3.4.2 Operation & Maintenance (O&M)

Operation and maintenance costs are country-specific and depend heavily on the company managing the plant. They include manpower costs, annual O&M investments, periodic equipment replacement, national and regional taxes, insurance and company overheads.

As O&M costs depend on a country's wages, public policy and the strategy of individual utilities and they are hard to estimate and compare.

O&M costs in Europe, based on different published studies for the three alternative base-load technologies

Country	Unit	Nuclear	Gas CCGT	Pulverized Coal
France[14]	€2001/MWh	7.2	5	9
Finland[15]	€2003/MWh	7.2	3.6	7.5
UK[16]	€2004/MWh	8	4.8	4.8
OECD range[17]	€2003/MWh	6.0 – 9.0	4.6 – 5.2	6.6 – 9

NB: exchange rates used: 1€ = 1.144US$ = £0.68

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[14] Ministry of Industry, DGEMP. Reference costs for the production of electricity, 2003, Paris, www.industrie.gouv.fr/energie

[15] Tarjanne R, Luostarinen K, Competitiveness of the electricity production alternatives (price level of March 2003), Lappenranta University of Technology, 20

[16] Royal Academy of Engineering. The Cost of Generating Electricity, A study carried out by PB Power for the Royal Academy of Engineering, UK, 2004.

[17] For Finland, France, Germany, the Netherlands and Switzerland

Annual O&M costs are not closely linked to the size of the plant or the level of electrical output. To maximise the benefit of load factor on total cost, utilities are likely to use larger plants for base-load, and thus improve the rate of return. The load factor is affected in turn by a number of largely predictable outages bearing on availability (e.g., re-loading, inspection or maintenance). These occur throughout the life of the plant and are affected by the O&M strategy.

Internationally, availability factors in excess of 90% are increasingly common, primarily due to shorter outages for refuelling. In particular, the US significantly improved capacity factor performance as operators have become more operationally adept.

3.4.3 Fuel Cost

Fuel costs include front-end expenses:

- Uranium purchase, conversion to fluoride, enrichment, fuel element manufacture, and back-end expenses;
- Spent-fuel management, high-level waste storage and final disposal; and
- Transport represents only a minor share of costs.

Generally, the power plant operator purchases uranium from mining companies and remains the owner of nuclear material throughout the whole fuel cycle. Services for conversion and enrichment are supplied on a globally competitive market. The fuel manufacture market is more regional. For spent-fuel management, the option of reprocessing is currently supplied on a global basis by three plants in Europe (France, Russia and the UK); the one in Japan is dedicated to national needs.

The uranium price shows some volatility as with other commodities. It was 20 US$/kg at the lowest in 2002, before rising steeply to more than 100 US$/kg in 2006. For the next 40 years, a range of 50 to 80 US$/kg seems likely, considering the expected start-up of new low-cost mines; which makes a uranium contribution of 1.5 to 2.5 €/MWh. Other front-end components (uranium conversion, enrichment, fabrication) are controlled by more stable technology costs, with ultracentrifugation dominating future enrichment services. Total front-end contributions amount to 3.5 to 4.5 €/MWh.

Back-end services include spent-fuel management (storage, reprocessing in some countries) and ultimate high-level waste conditioning and disposal. The cost varies from 1 to 4 €/MWh.

Fuel Costs in Total Generating Cost
(excluding CO_2 cost and including back-end)

	Nuclear	Gas CCGT*	Coal**
Fuel (€/MWh)	4.5 to 8.5	27 to 45	15-22

* *CCGT efficiency = 60% on LHV, gas at 3.6 to 6.0 Euro/Gigajoule*

** *Coal plant efficiency = 42% on LHV, coal at 45-70US$/ton CIF, 6000 kcal/kg*

Fuel is a smaller proportion of nuclear generating cost, than it is for gas or coal. As the uranium price is about 30% of the fuel cost and less than 10% of the overall cost of nuclear generation, the latter is not sensitive to movements in commodity prices. A doubling of fuel prices would increase marginal generating cost at a gas plant by 70-80%, while the cost at a nuclear power station would only increase by 5% or 10% at most. When the uranium price reaches US$50/kg, the contribution to total generation cost is about 1.5 €/MWh. Even when assuming a long-term price of US$200/kg, in case of resource shortages, uranium contribution would only reach 6 Euros/MWh.

An Example of Uranium Price Influence on Generating Cost (€2001/MWh)

Uranium price **Generation cost**	**26 USD/kg**	**52 USD/kg**	**104 USD/kg**
Fuel *(burn-up 60 GWd/t)*	***3.7***	***4.4***	***5.9***
Total	*27.7*	*28.4*	*29.9*
	-2.5%	**-**	**+5%**

Source: DGEMP 2003, 8% discount rate, 1€ = 1 US$, Series of EPR, fuel (NB These estimates include all front-end expenses, as well as back-end provisions for used fuel management.)

NPPs therefore produce power at stable and predictable costs, reducing the volatility for utilities. Although difficult to quantify, this stability is valuable as a hedge against fossil fuel prices.

3.4.4 Decommissioning Cost

The final costs of decommissioning vary significantly among countries and plants, due to differences in public policy, plant design and size. Estimates of decommissioning costs for existing and planned plants range from 250 €/kW to 1000 €/kW, reflecting differences in reactor technologies, series effect, country legislation and regulatory bodies involved.

For example, EdF uses 15% of total investment cost in real terms, as a guide to decommissioning cost. This was recently verified, by a detailed cost forecast for decommissioning the Dampierre plant (4x900 MWe pressurised water reactor), including deconstruction, engineering, monitoring, maintenance, site security and packaging, transporting and disposal of waste. EdF has estimated that an EPR in France would cost approximately 450 million Euros (M€) to decommission. This figure is drawn from a room-by-room assessment with information gathered from the current fleet, using the cost of replacing parts to generate data.

On the other hand, the cost for dismantling an older, smaller 160 MWe reactor, Zorita in Spain, has recently been estimated by Union Fenosa at 135 M€, i.e., 850 €/kW and the dismantling of the German plant Obrigheim was estimated at 1,400 €/kWe (357 MW). Dismantling in Germany is more expensive especially for small plants.

When provisions are spread over the lifetime of a plant (60 years in the case of Generation 3), decommissioning costs do not fundamentally alter the economics of nuclear power. The cost of decommissioning, once discounted to the initial time of decision, represents a small fraction, e.g., 3%, of investment. For most reactors to be built, the contribution of decommissioning to the levelised lifecycle generation cost would be 0.5 to 1 €/MWh at most. Hence, prudently managed, decommissioning costs are not a financial obstacle to building new plants.

3.4.5 Conclusion: Best Estimated Cost Ranges

Nuclear generating costs are estimated in the following ranges:

- O&M: from 6 to 9 €/MWh;
- Fuel front-end: 3.5 to 4.5 €/MWh;
- Fuel back-end: 1 to 4 €/MWh;
- Decommissioning: 0.5 to 1 €/MWh;
- Capital cost contributions strongly depend on the discount rate, related to financing conditions, generally summarised as the weighted average cost of capital (WACC). Assuming an OVN cost of 1800 €/kW, the capital cost contribution can vary from 14 €/MWh to 40 €/MWh depending upon financing conditions;
- Thus for total cost, the range would extend from 25 to 55 Euro/MWh, depending on the capital cost. The best estimate for a central value would be around 40 Euro/MWh.

Time discounting is the usual practice for assessing cash flow generated by a new project over it total lifetime. The main criteria used for investment choices and decisions are the Net Present Value (NPV) and the Internal Rate of Return (IRR) of the project.

They are calculated using the following equations:

Net Present Value (during total economic life):

$$NPV = \Sigma \text{ Income } i / (1+DR)i - \Sigma \text{ Expense } i /(1+DR)i$$

Each amount is discounted relative to a reference year, generally the first operating year of the plant. DR is the discount rate expressing a preference for the present.

Income

$$\Sigma \text{ sales } i / (1+DR)i = p \times \Sigma\, Qi / (1+DR)i$$ where Qi is yearly generation and p the electricity price

Set NPV = 0

For a given DR, the discounted levelised generation cost is the value of price p setting NPV =0

When the electricity price (p) is fixed, DR value setting NPV = 0 is the internal rate of return (IRR) of the project.

If p = discounted levelised cost, then DR = IRR before tax

When comparing different power generation technologies before investment, at least two methods are applicable for assessing the lifecycle cost of electricity (LCOE):

- A general economic method, ignoring specific project conditions (location, taxes, company's access to capital). A general discount rate is used. Values are in real terms. This method is used by government and international organisations for a comparison of options;
- A financing method, which takes into account national taxes and financing conditions for investors. This method uses an amortisation time scale and a type of amortisation (linear and non linear). Calculations are performed in nominal terms using an inflation rate. This method is used by private companies, utilities and independent power producers (IPPs) for specific projects.

In the first case (public point of view), economic assessments feeding national policy should account for all social costs:

- Generation costs;
- External costs of environmental and health impacts.

Conversely, income tax and other taxes are not included in the generation cost (net flow = 0 for the country).

Discount rate values reflect the average return on capital in the country.

In the second case (private point of view), total costs include taxes but no external cost (by definition). Income tax has a special importance, depending on how financing of the investment is ensured (relative shares of equity and debt). Here the concept of weighted average cost of capital (WACC) comes into the equation.

Capital is supplied by a combination of equity funding and bank loans. The resulting cost of financing depends on returns required by investors: return on equity (ROE) for equity and interest rate (r) for the loan. It is given as WACC, Weighted Average Capital Cost:

$$\text{WACC} = (\%\text{equity}) \times \text{ROE} + (1 - \%\text{equity}) \times r$$

WACC may be given before or after tax (on income), in real or in nominal terms.

WACC Real before tax:

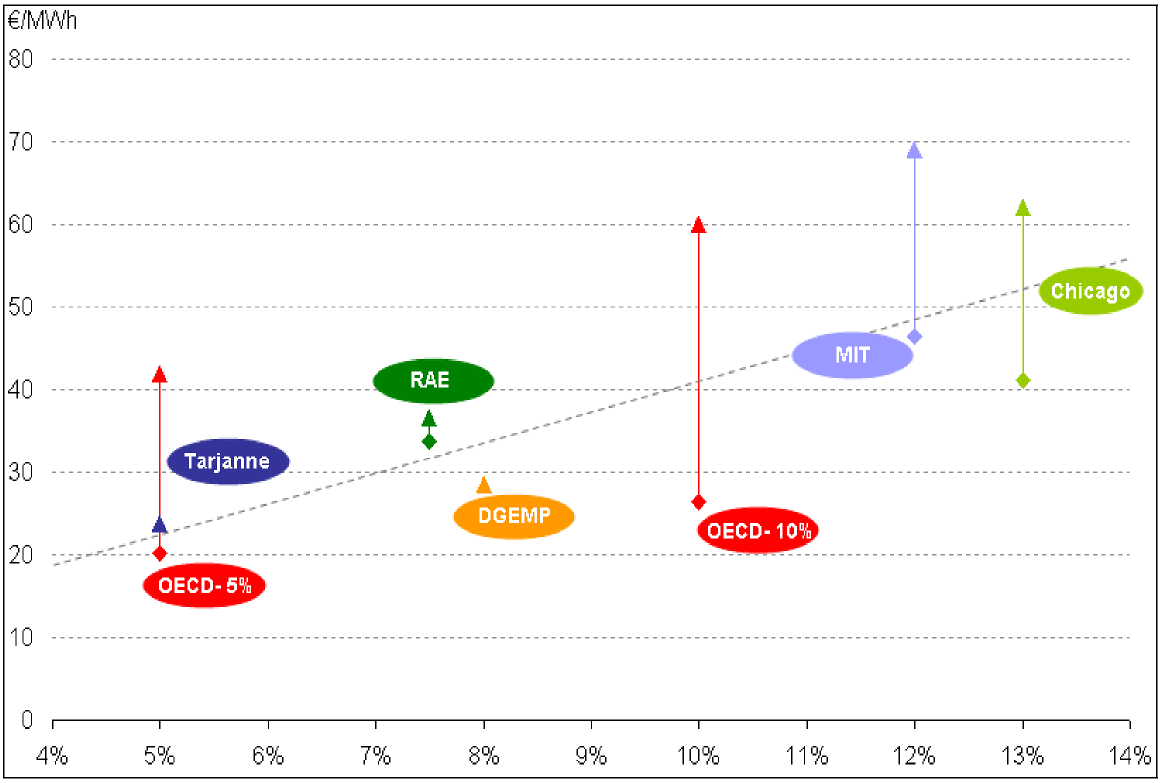
$$[\%\text{Equity}*\text{ROE real}/(1-\text{tax})]+ [(1-\%\text{Equity})*\text{loan rate real}]$$

Since the required ROE is generally higher than r, leveraging by a higher percentage of a loan is favourable, but is only accepted up to a certain limit by most banks.

The Return On Invested Capital (ROIC) of any project should be at least equal to WACC. The value required for IRR is thus governed by WACC. Setting IRR = WACC before tax means WACC is identified to the discount rate (DR) value, setting the Net Present Value at 0 for a given sales price.

3.5 Discussion on Financing and Discount Rate Values

The cost of capital as expressed by WACC strongly influences total generation cost. A new nuclear build is a highly capital-intensive project, in which attractiveness is sensitive to the cost of capital. This means financing conditions are a key to future nuclear deployment. This can be summarised by the following chart, showing the relation of generation cost to real pre-tax WACC value, as evidenced by recent studies in Europe and in the US.



Sources: OECD NEA/IEA (2005) Projected cost of generating electricity, 2005 Update. French DGEMP (2003) Coûts de référence de la production électrique. Royal Academy of Engineering (2004) The cost of generating electricity. MIT (2004) The Future of Nuclear Power. Chicago (2004) The economic future of nuclear power. R. Tarjanne (2005) Electricity Generation costs of nuclear, coal, gas, peat, wood, and wind power.

3.5.1 Finding Reference Values for the Cost of Capital (WACC)

Some years ago, average WACC values for European electricity companies were assessed by the economists of CGEMP-Dauphine University, in Paris. This study based on the 1996-2000 annual reports of the selected companies, was published in 2003 and showed an average ROE of about 12% nominal after taxes. Derived WACC values are shown in the following table. Such values correspond to pre-tax real WACC values of about 8% (with an inflation rate of 2%).

- ***Weighted Average Cost of Capital (WACC) for some European utilities (nominal after tax)***

Company	2000	1999	1998	1997
Iberdrola	6.1%	6.2%	7%	8.3%
Endesa	6.3%	6.3%	7.1%	8.5%
RWE	6.4%	6.4%	7.3%	9%
Tractebel	6.6%	6.8%	7.4%	8.5%
EVN	5.9%	5.9%	6.9%	8.9%
Verbund	6%	6.1%	6.8%	6.6%
Electrabel	6.5%	6.5%	7.4%	8.6%
Veba	6.2%	6.3%	7%	8.7%
Viag	6.1%	6.1%	6.7%	7.6%
EDP	6.1%	6.1%	6.5%	7.4%
Hidro Cantabrico	6.4%	6.4%	7.2%	8.6%
Union Fenosa	6.8%	6.8%	7.4%	8.7%
Mean	6.28%	6.33%	7.06%	8.20%

Source: «Dauphine» Economies et sociétés. Tome XXXVII, N°2-3, Fév.-Mars 2003, Isméa Les presses.

Since the end of the 1990s, the costs of capital have changed. Two forces are acting in opposite directions:

- On one hand, effective liberalisation of electricity markets have induced higher requirements on return on capital (ROE);
- On the other hand, loan rates in real terms have remained at historically low levels; and mergers have resulted in larger companies, able to easily attract capital.

Indicative reference values for WACC

We calculated a reference case, assuming the following real values before tax:

- Interest rate: European power companies have access to bank loans at a rate of around 5%;
- Return on equity: 12 to 15% nominal after tax, 14 to 18% real before tax;

- Debt to equity ratio: around 50/50.

Assuming further:

Financing = 40% equity, 60% loan
Return on Equity = 12% after income tax
Loan rate = 7% nominal
Income tax = 35%
Inflation = 3%

Then WACC before tax = 7.7% real

We compare this with some observed cases:

EdF (2005) uses a value of 8 to 9%.

The WACC value of 5% to 6% has been used by R. Tarjanne (Lappeenrata University) in the context of the TVO Olkiluoto project in Finland.

Merrill Lynch, in its evaluation of British Energy (January 2005), takes a "relatively high" nominal value WACC = 10%, i.e., about 8% real.

In the UK, PB Power also used a 7.5% value in 2004 (a study conducted on behalf of the Royal Academy of Engineering), then 10% value was used in 2006, in the context of the National Energy Review. The economic study (by NERA and Sussex University) included in the Sustain Development Commission assessment of nuclear power, is based on a discount rate (i.e., WACC before tax) value of 9% real.

- ***Key Conditioning Factors***

The cost of capital (WACC) depends on the condition of the electricity company. Large, well-established companies have access to low loan rates and high gearing (debt/equity) from financing institutions. It also depends on the country's taxation policies: the higher the rate of income tax, the higher IRR before tax should be. Consequently, heavy investments are especially difficult for newcomers to the power market, small independent power producers (IPP) and in countries imposing high tax rates.

Finally, the financial corporate performances of others in a given country also drive shareholders' expectations on the return on equity (ROE). A current standard of expectations is an ROE of 15%. However, the electricity sector has not yet yielded such profit levels over a long period, either in the US or Europe. Nor is it certain that such levels are achievable in a sector combining high capital intensity, reinforced competition and no mining rent.

- ***The Risk Premium***

It is often argued that higher returns are required from nuclear projects, than from coal or gas-fired plants, due to a greater degree of risk. As a consequence, a specific risk premium of about 3 to 4% is suggested, both on debt interest rate and ROE. Also, the percentage of equity required by the banks in project financing is assumed to be higher. The risk premiums suggested by three studies are shown as follows:

1) MIT 2003

In real terms - income tax = 38%

	% equity	Net ROE After tax	Net ROE Before tax	Interest rate	Resulting WACC before tax
Nuclear	50%	12%	19.0%	5%	**12.0%**
Coal and gas	40%	9%	14.5%	5%	**8.8%**

2) University of Chicago 2004

In real terms - income tax = 38% - no nuclear policy

	% equity	Net ROE After tax	Net ROE Before tax	Interest rate	Resulting WACC before tax
Nuclear	50%	12%	19.0%	7%	**13.0%**
Coal and gas	50%	9%	14.5%	4%	**9.2%**

3) EFF 2005 (UK)

EFF, The Manufacturers' Organisation: Sustainable Energy, A Long-Term Strategy for the UK"

WACC before tax is assumed at 7.5% for coal and gas plants, versus 12% for nuclear plants and windmills. Not surprisingly, when WACC is equal to 11% or even 13%, highly capital-intensive technologies such as nuclear, renewables and integrated gasification combined cycle (IGCC) clean coal, are found to be non-competitive.

3.5.2 Risk Analysis Governing WACC Value

The key point is that risk perception initiates a vicious circle: the more risky a project is perceived to be, the more costly financing becomes, through a higher WACC value, making it even more risky in financial terms. This point should be stressed; confusion between different categories of risk should be avoided. We propose a review of both the main risks identified, as influencing the cost of financing (both the loan rate and the return on equity).

3.5.2.1 Market risk

Market risk is not specific to nuclear projects. Indeed, in 2001-2002, it was also high for combined cycle gas turbine (CCGT) projects in the US; it was launched in excess of what could be absorbed by the market. In fact, considering the current volatility of natural gas prices, the market risk is greater for CCGT than coal or nuclear plants, especially since the CCGT load-factor is restricted by higher marginal cost.

Currently, observed forward prices for base-load power are converging towards CCGT Long Run Marginal Cost (LRMC), above 40 €/MWh (possibly even 50 €/MWh), due to gas price increases and anticipated CO_2 emission costs. The indicative level of cash cost for operating nuclear power plants shows that, once in service, they benefit from high load (merit order) and operating margin. Conversely, CCGT units suffer from cash costs higher than 30 €/MWh and are subject to mothballing first when prices fall.

As a rough rule, the market price is likely to vary between the threshold levels of CCGT short run marginal cost (SRMC) when capacity exceeds demand and the ceiling level of the long run marginal cost (LRMC) of a total new CCGT. Indicative values for SRMC are given in the table below; for the corresponding LRMC, a cost of 5 €/MWh for investment should be added.

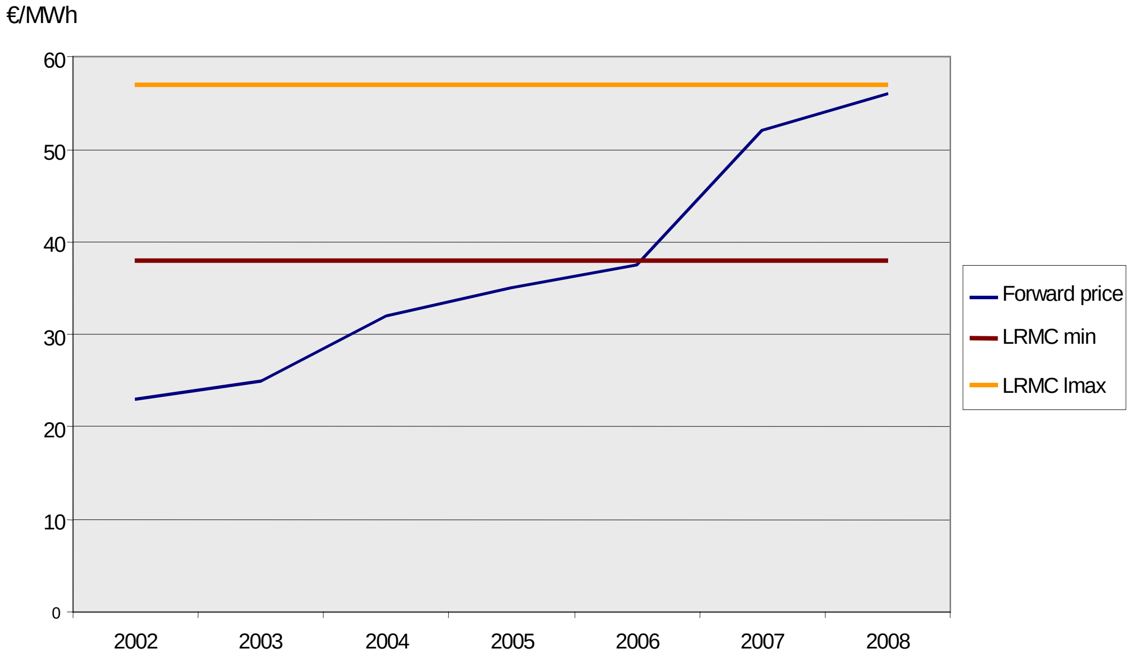
SRMC cost (O&M + Fuel) of CCGT, under which level CCGT plants would be mothballed (assuming a thermal efficiency of 59%):

CO_2 price, €/t Gas price €/GJ	7	20
4.0	***33 €/MWh***	***38 €/MWh***
5.0	***40 €/MWh***	***45 €/MWh***
6.0	***47 €/MWh***	***52 €/MWh***

A new plant will be profitable with low market risk, if the total average lifecycle cost is below the lowest anticipated electricity price, i.e., the anticipated level of CCGT SRMC.

The validity of this analysis can be checked through observed market behaviour and moving prices. Observed forward prices (year n+1 and n+2) on the German wholesale electricity market (e.g. the following chart) can be compared to costs given, in the table above. On the chart, the evolution of forward prices since 2002 is compared to the minimum level of 38 €/MWh (LRMCmin) and to the maximal level of 57 €/MWh (LRMCmax). It indicates that markets have quickly moved from a situation of overcapacity, before 2002 (prices fixed by SRMC of CCGT) to the need for new capacity with an anticipated cost of LRMCmin before 2005, then with an anticipated cost around LRMCmax. The move is a consequence of soaring gas prices, combined with the implementation of the European Trading System for CO_2 emissions.

Forward Prices in Germany



Source: Platts, June 2006

To conclude the question of market and price risk, it is worth underscoring that all new base-load generation investments depend on the ability to mobilise sufficient capital. No matter if it is coal, hydro or nuclear power plants, all are big projects that require long-term contracts. Gas turbines themselves are dependent for fuel supply on big gas transport projects. The merchant plant is not an easy model for base-load power plants whatever the technology, since it means a high-risk premium on financing. The US market has shown a number of bankruptcies of major merchant plant companies, despite relying on low investment CCGT technology. More appropriate business models are found either in the TVO case, based on a nexus of long-term contracts with municipalities and industrial customers, or in large and diversified utilities able to finance new projects mainly on their balance sheet.

3.5.2.2 The Regulatory Risk

Each investment in power generation is subject to the risk of changing regulations, on electricity market rules, on taxation, on environmental protection. Examples include reduced levels of pollutants in stack discharges from fossil fuel plants and more drastic safety rules for nuclear plants. Coal plants are subject to an additional risk related to greenhouse gases (GHG) emissions control. The cost of CO_2 emissions may rise up to 15 €/MWh for the best performing plants (emitting no more than 800kg CO_2/MWh) or even beyond in the European Trading System.

There are, however, some specific (idiosyncratic) risks that affect nuclear plants more than other fuels, or which apply only to nuclear projects.

3.5.2.3 The Lead Time Risk

Licensing processes, site preparation and construction works may be subject to delays. Considering the weight of upfront expenses in the project balance for nuclear plants, such delays can have a significant impact on profitability. Investors must be persuaded that they can be avoided.

Failure to complete construction on time and within budget has occurred more than once. Very severe delays and high extra costs were experienced in the US, but less so in Europe.

Several options for new Generation 3 models are designed to minimise this kind of risk:

- The need to include features required by the Safety Authorities, to reduce core damage frequency and accommodate severe accidents and external hazards with no long-term effect on the local population;
- Simplified operation and maintenance;
- Complying with the specified European Utility Requirements (EUR); and
- Developing evolutionary designs to take advantage of construction, operating and research and development (R&D) experience available throughout the industry.

3.5.2.4 The Political Risk

Public acceptance remains uncertain in many countries. ‘Is nuclear power safe enough?’ is it “confidence building” enough? Is there a risk of strong, social and political opposition? The national environment must be supportive. Clear political commitment and steady energy policy are pre-requisites and such conditions have been met in Finland and France where decisions have been recently taken.

In the US, the Energy Bill enacted in August 2005, establishes several institutional and fiscal tools to foster new nuclear builds. According to recent opinion polls, local public acceptance seems favourable (more than 70%). Currently, this issue has been subject to public debate in the UK.

3.5.3 Conclusion

In Europe and in North America, the conventional wisdom shared by financial analysts is that the first ones to build new plants will be large nuclear companies with strong financial performance records and excellent records as nuclear operators. Such companies should have no major difficulties in turning to the financial markets for additional debt and equity financing. Decisions are easier, if they are supported by “cost of service” regulation or long-term power purchase contracts.

In the future, the risk perceived by investors is likely to decrease as a result of:

- Demand/supply balances inducing high electricity market prices;
- Successful projects achieved by the “first movers”;
- Improved public acceptance, if world safety records remain on the track of excellence;
- International “opinion spiral move” reversed from a negative to a positive direction.

Risk is also relative to alternative options. Nuclear energy benefits from the following features:

- The low marginal cost of production warrants a priority for dispatch into the grid, which means a high-load factor;
- Fuel supply security (sources, storage, recycling);
- Fuel contribution to total cost is small, allowing long-term price stability;
- No risk of CO_2 emissions-related costs from emerging climate change policies, whereas a 20 €/tCO_2 results in extra costs of about 7 €/MWh on CCGT and 20 €/MWh on coal-fired plants;
- The external costs of nuclear power are among the lowest of all electricity-generating options (cf., ExternE study in Chapter 1).

Governments have a key role in establishing and developing informed public debate on different energy options, they could promote more balanced risk assessments.

3.6 Regulatory Framework and Licensing Procedures

A condition for nuclear energy development in any country, is the existence of a clear, well-established regulatory framework, which addresses the following:

- Safety requirements and control;
- Reactor licensing;
- Site permits;
- Discharge authorisations;
- Waste management and disposal; and
- Decommissioning rules and financing.

A predictable and efficient licensing process, in terms of outcome / time span is required to support decisions on new projects. The expected licensing and siting process and time schedule can be illustrated by two recent examples in Finland and France. The comprehensive regulatory framework recently established in the US is also a good example of improved systems, aimed at simplified, shorter procedures.

3.6.1 The Finnish Case – Olkiluoto 3

3.6.1.1 Summary of Key Milestones

- Pre-review and feasibility studies of available designs by the Finnish utilities and the authorities, since April 1998;
- The programme for Environmental Impact Assessment (EIA) submitted in June 1998
  - Statement of the Ministry of Trade and Industry on the final EIA report in February 2000.
- TVO submits the Decision-in-Principle (DiP) application in November 2000;
  - Positive decision by the Government in January 2002,

  - Decision ratified by Parliament in May 2002.

- TVO launches bidding competition in September 2002,
  - Bids received March 2003,
  - TVO selects the site and AREVA-Siemens as preferred bidder, October 2003,
  - Investment decision and signing of main contract, December 2003.

- Start-up of site preparation in December 2003,
  - Site handed over to the plant supplier, February 2005.

- Filing of construction licence application January 2004,
  - Licence granted by the government, February 2005.

- Casting of reactor base slab, October 2005.
- Start-up of installation – 2006.
- Filing of operation licence application – 2007.
- Commissioning in 2010.
-

3.6.1.2 Comments on Different Licensing and Project Phases

The Finnish example allowed a quick instruction phase for delivery of the construction licence (14 months between the contract signature and construction licence issuance). This summary indicates the information delivered publicly by the key Finnish entities[18].

The main components of the Finnish approach are:

- A feasibility study of "candidate designs", to ensure the absence of safety issues preventing compliance with Finnish nuclear safety regulations;
- A well-defined regulatory context;
- An EIA performed in advance, with decoupling of data to ensure validity independent of different reactor designs and to provide information supporting the political approval process; and
- A political approval process in advance of the industrial decision process.

Feasibility studies

The Finnish utilities and the Centre for Radiation and Nuclear safety authority (STUK) gathered information for many years on most of the alternative plants, presented in the DiP application and made a statement shortly, when the process became formal.

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[18] e.g: Websites of STUK: www.stuk.fi, of the Finnish ministry of trade and industry www.ktm.fi, of the Finnish Parliament www.eduskunta.fi

To support the process, the Finnish utilities reviewed compliance with the Finnish regulations with the potential vendors and worked on other matters of interest with a view to possible construction. The main topics of this feasibility study were:

- Assessment of the licence ability of the design under Finnish conditions:
- Main components;
- Building structures and layout;
- Conventional Island;
- Construction;
- General considerations; and
- References.

Safety assessments of the potential suppliers and the utilities were presented to the STUK, which used this information and other data to derive its conclusions. STUK concluded that alternative designs mentioned in the application could probably be made to fulfil Finnish safety requirements, but none of the plants seemed acceptable as presented and some modifications would be needed in all designs.

After the statement was issued, the events on 11 September 2002 took place (in which two airliners were crashed into the two World Trade Centre buildings in New York City, US), and the Ministry responsible for nuclear licensing asked STUK, whether it was possible to provide protection even against severe plane crashes. STUK issued new safety requirements on external impacts and concluded that it was feasible to meet them.

EIA of a new plant

The first step for licensing a new nuclear plant unit was the Environmental Impact Assessment (EIA):

- Started in June 1998, completed February 2000.
- Early execution of the EIA is consistent with the overall licensing process, providing useful data for the government to make a Decision in Principle (DiP).
- STUK considers that the EIA does not require detailed and specific information on specific plant type. The EIA assumes operation from existing nuclear units but based on safety requirements for a new plant.
- EIA were conducted separately by two utilities for the two potential sites. Both sites already have nuclear plants in operation.

Political approval process

The DiP application was filed in November 2000, listing seven possible alternatives for the new plant. The main criteria for DiP approval is that a new installation meets "the overall good of society". This decision must be made by the Government, and after the decision, ratification by Parliament is required by law. There are two mandatory conditions that must be met before a decision can be made. First, the regulatory body, STUK must state that no safety issues can be foreseen, that would prevent the proposed plant(s) from meeting Finnish nuclear safety regulations. At the same time, the proposed host municipality had to agree to provide the site.

After this phase, the two other licensing steps following the DiP, are similar to common worldwide practice: application for a construction licence and an operating licence. These instruction phases are then driven by technical considerations.

The Finnish Government made a DiP in January 2002, concluding that construction of a new nuclear power plant in Finland was "in line with the overall good of the society".

- The Finnish Nuclear Energy Act states that a DiP is required before the industrial project can be started. The purpose is to obviate political interference with the regulatory process, once the DiP is gained.
- The DiP is thus the final step of the political decision-making process and authorises TVO to continue preparations on commercial and technical levels for construction of a new nuclear power plant.

The next step was discussion and possible ratification by Parliament. In case of a negative Government decision, the issue would not have been submitted to Parliament.

The political parties were split in this matter, except the Green Party, and the intent was to have a detailed Parliament discussion of the final decision.

The Government gave the following supporting arguments for a new nuclear power plant:

- Importance for electrical power supply;
- Together with energy savings and increased use of renewable power sources, a new nuclear plant could keep the greenhouse gas (GHG) releases within the agreed target;
- STUK’s positive statement on nuclear safety;
- Site suitability and acceptable environmental impact;
- Adequate arrangements for supply of nuclear fuel and management of nuclear waste;
- Full private funding; and the
- Ability of the applicant to implement the construction project.

The new nuclear plant was the most-discussed topic in Parliament, in spring 2002. Members of Parliament made a thorough assessment in eight standing committees. From 200 Parliament members, 115 worked in one or more committees, during spring 2002. Each committee heard reports from a large number of experts invited for interviews. Experts representing a full spectrum of views on nuclear energy provided different viewpoints.

Arguments listed for the Parliament’s plenary session, in favour of a new nuclear unit were as follows:

- A new plant would help maintain multiple sources for power production, thus increasing self-sufficiency and improving preparedness for crisis;
- Nuclear power is competitive;
- Accident risks are small;
- There are no atmospheric releases and environmental impact is small;

- From the standpoint of national economics, nuclear power is the best way to reduce carbon dioxide releases;
- Nuclear fuel supply and nuclear waste management can be arranged using existing infrastructure;
- The only realistic alternative to a new nuclear plant would be increased use of gas for power production, but this would strongly increase dependence on imports and increase the power price and the need for state support to the energy sector.

Furthermore, the Finnish Parliament had one year earlier, in May 2001, almost unanimously ratified the DiP for construction of a final disposal facility for spent nuclear fuel.

The result of the vote on a new power plant unit in May 2002, was 107 in favour and 92 against.

Public opinion that had been balanced for and against a new nuclear plant, changed significantly after DiP ratification. A poll conducted among the general public immediately after Parliamentary ratification, indicated that a clear majority of those questioned approved the decision. Editorials in all larger newspapers welcomed the decision in a positive spirit; according to a study for the Ministry of Trade and Industry, not a single major editorial took a negative position on the decision.

Steps of implementation

After conclusion of the political process, the industrial process was started by TVO. The technical requirements in the tender documents issued in September 2002 were derived from the European Utility Requirements (EUR) document as a reference. The application of the EUR[19] document, compiled in co-operation among utilities from several European countries represented a new approach. TVO’s specifications complemented the EUR mainly in areas where Finnish requirements are specific. Technology and site specifications were decided in October 2003. The contract was signed on 19 December 2003 between TVO and the Consortium AREVA NP - Siemens, led by AREVA NP, for turn-key delivery of an EPR (1600 MWe) to be built on the Olkiluoto site. The application file for the construction licence was submitted by TVO, in January 2004. This licence was awarded on February 2005 by the Finnish Government. The next licensing milestone will be application of the operating licence, to be submitted in 2008. Start-up of electricity production is scheduled for 2010.

3.6.2 The French Case (Flamanville 3)

The basic design of the EPR was extensively reviewed by the safety authorities and their support organisations, IRSN (French Institute for Radiological Protection and Nuclear Safety) and GRS (Germany’s central expert institution for nuclear safety). This review gave rise to a set of technical guidelines, drawn up by the "Groupe Permanent Réacteur" (French Advisory Group to the Safety Authorities – GPR) together with German experts and submitted to the French safety authorities, in November 2000. On 28 September 2004, this document was officially endorsed by DGSNR through a letter

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[19] www.europeanutilityrequirements.org/eur

signed, on behalf of both Ministers overseeing nuclear safety (the Minister of Industry and the Minister of Environment).

In September 2004, the DGSNR also officially fixed the safety objectives to be satisfied by the next generation of PWRs, to be licensed in France. During 2005, the DGSNR evaluated the detailed design of specific features identified by the French Safety Authorities, as requiring additional attention for future licensing. This on-going assessment is in preparation for the formal licensing process, which will begin when EdF submits the official application for the construction licence.

EdF officially announced the selection of the Flamanville site in October 2004. As required by French law, a public debate was organised to gather comments from stakeholders, with regard to the proposed construction of an EPR unit on the Flamanville site, next to the two 1300 MWe units in operation. This debate was concluded in February 2006. The commission in charge organised national as well as local debates, and enlarged the scope to general issues already discussed, during the national debate on energy policy in 2003. After this step and after considering the results of the public debate, EdF confirmed its decision and formally asked an authorisation of creation to the French Safety Authority on 4 May 2006. The French government started the public enquiry on 15 June 2006.

According to French Law, the procedure to obtain authorisation for creating a new “basic nuclear installation” (INB) is defined by the French Ministerial Decree of 11 December 1963. It includes:

- Sending the authority a preliminary safety report (PSR) describing the installation on-site, the operations to be carried out, the inventory of risks from all origins, the analysis of steps to be taken to prevent risks and specific measures to reduce the probability of accidents and their consequences;
- Presenting a dossier for use in public enquiries, comprising drawings of the facility, the risk analysis and the environmental impact study, and measures towards decommissioning, based on the PSR.

On 29 September 2006, the legal period of enquiry ended, the committee leading the public enquiry concluded, in favour of the Flamanville 3 project.

3.6.3 The US Case (No Construction Commitment Yet)

- Three new licensing procedures are being tested to overcome past regulatory difficulties and delays:
    - An early site permit (ESP) set up for early resolution of site related issues (3 ongoing);
    - Reactor design certification (DC), valid for 15 years, set up for early resolution of reactor design issues (4 designs certified today, 2 more under review);
    - Combined licence (COL) authorises one-step construction and conditional operation, which may refer ESP and DC in principle, to shorten the approval process, whilst maintaining the public right to intervene (8 COL under preparation).

The main purpose of these measures are to encourage early resolution of issues, to increase regulatory predictability, in advance of major financial commitments, whilst maintaining the requisite safety reviews. According to the US Nuclear Regulatory Commission (NRC), the new process should move all regulatory approvals to the fore, prior to significant capital expenditures and raise the threshold for intervention after granting COL.

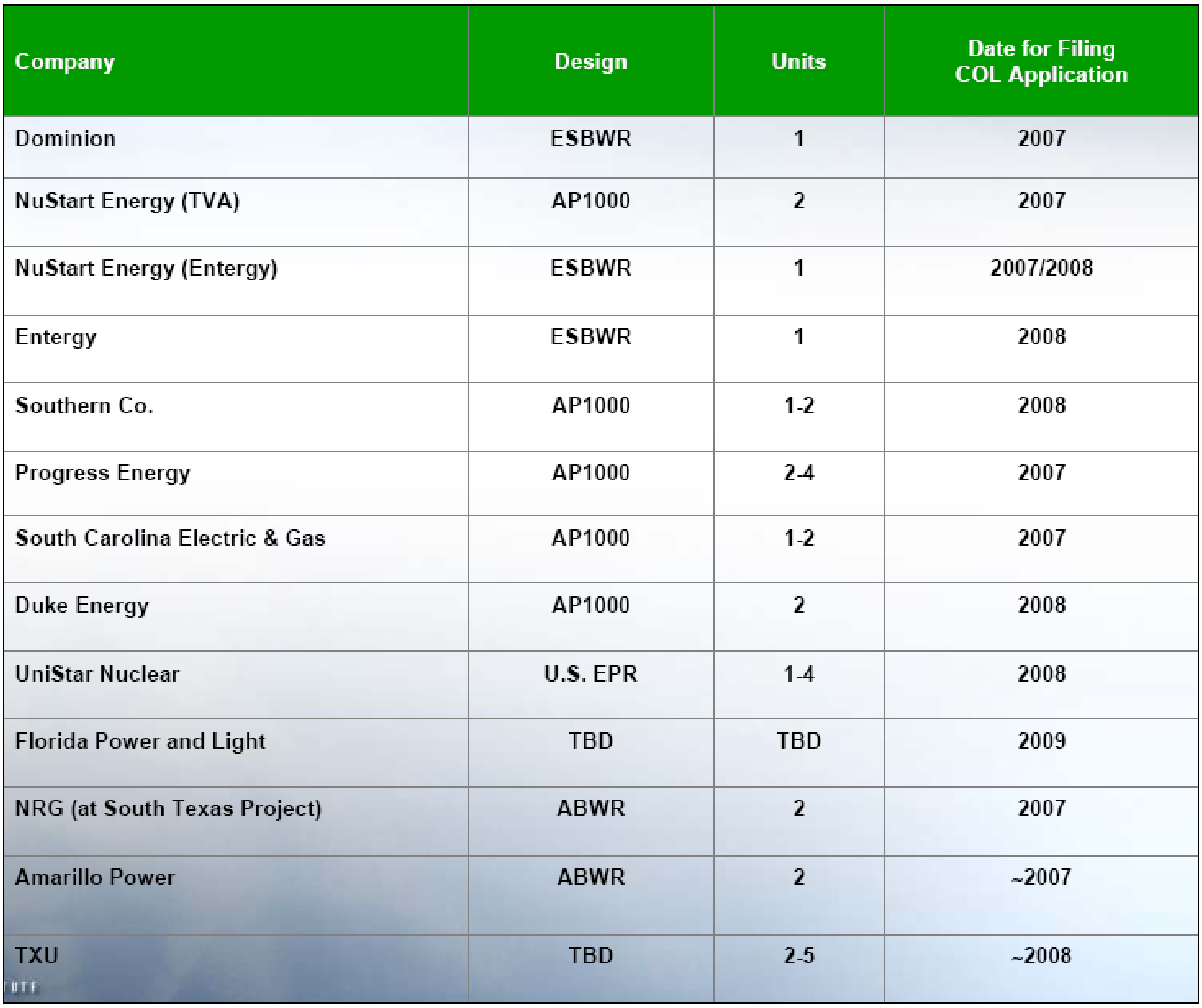
Estimates of the time required for each step of this new process (including preparation, reviews and hearings) are as follows:

- DC ~39 months;
- COL with DC + ESP available ~42 months;
- COL on an existing site, with DC but no ESP ~63 months;
- COL on a greenfield site with DC but no ESP ~69 months.

US utilities are presently selecting existing nuclear reactor sites for planned ESP and/or COL. This choice greatly simplifies resolution of site related issues for a new build, as many of them are already known (geology, seismicity, meteorology, heat sink capability) or are under control (emergency planning).

The first step of a utility would be to apply for and obtain an ESP. Based on this ESP plus a reactor design, and having obtained a Design Certification (DC), the utility would apply for a combined operating licence (COL). However, until now, many of the COL applications being prepared by US utilities do not strictly comply with the new licensing process. Several have not been preceded by an ESP application, so that ESP and COL will be combined in one single and likely longer procedural step. The same problem would apply in other cases where COL and DC are conducted in parallel. These facts led the NRC in 2006, to open a rulemaking process to make the anticipated application reviews as effective and efficient as possible.

Current declared expressions of interest in the USA (as of November, 2006)



Company	Design	Units	Date for Filing COL Application
Dominion	ESBWR	1	2007
NuStart Energy (TVA)	AP1000	2	2007
NuStart Energy (Entergy)	ESBWR	1	2007/2008
Entergy	ESBWR	1	2008
Southern Co.	AP1000	1-2	2008
Progress Energy	AP1000	2-4	2007
South Carolina Electric & Gas	AP1000	1-2	2007
Duke Energy	AP1000	2	2008
UniStar Nuclear	U.S. EPR	1-4	2008
Florida Power and Light	TBD	TBD	2009
NRG (at South Texas Project)	ABWR	2	2007
Amarillo Power	ABWR	2	~2007
TXU	TBD	2-5	~2008

Source: NEI

3.6.4 National Regulations Across Europe: Towards Harmonisation

The main principles of nuclear safety in all countries are identical. However, these principles are applied differently, which can lead to differences in the safety requirements, or even different levels of safety. One reason is that safety approaches have evolved gradually with successive generations of experience at nuclear facilities, whereas in the beginning, they were developed by the designers of chosen technologies.

Today, a number of strong interests are converging to take nuclear safety harmonisation a step further at a European level, for power reactors, and for fuel cycle facilities, the disposal of radioactive waste and the dismantling of nuclear facilities. In the long-run, there is no reason for requirements for protection of the public and the environment to be significantly different in countries with comparable levels of economic and technological development.

Operators and authorities both share the goal of harmonising nuclear safety requirements across the EU, because it will enhance public confidence in nuclear safety and an open electricity market means power producers follow similar rules of operation and supervision throughout Europe. For new designs it allows simplified licensing procedures in one country, when the design has been approved and certified elsewhere.

Currently, the international common basis is limited to the basic safety standards issued by the International Atomic Energy Agency (IAEA). Within the EU, the Commission has proffered draft directives (a “nuclear package”) attempting to harmonise national regulatory practices for nuclear safety principles and radwaste management. However, an attempt to legally bind European texts failed (European Council decision, June 2004) due to a lack of consensus among Member States.

The WENRA (Western Europe Nuclear Regulators Association) comprises of 17 national nuclear authorities in Europe. It has now evolved from encouraging technical exchanges between regulatory authorities to more ambitious harmonising actions targeting common safety reference levels. In EU-25, WENRA found that 88% of the adopted reference levels for reactor safety are already implemented at all 163 nuclear reactors, even though more than half of the levels are still to be translated into national regulations. This indicates proactive and responsible behaviour on the part of operators, a reflection of their strong safety culture. Discussion continues between WENRA and the operators on some of the reference levels and on ways to apply them to older reactors for which the high cost of strict compliance would imply heavy refurbishment or early closure (e.g., MAGNOX reactors). But convergence can be expected around 2010. Until now, WENRA has only dealt with operating plants, but has expressed the willingness to address new designs and new builds. Beyond 2010, possibly new projects would be decided in a more harmonised regulatory context across Europe.

3.7 Industrial and Technical Infrastructure

Developing a nuclear power programme in any country is premised on its being embedded in a well established infrastructure of scientific, technical, administrative and industrial means. Most important are:

- The available technical expertise in support of the safety authority;
- R&D and testing platforms (for materials, mechanical components, etc);
- Qualified operators and training benchmarks; and
- Industrial facilities for equipment manufacturing and fuel services.

Part of these can be shared at the European level: industrial facilities, reactor operating-simulators for training, material test reactors and hot laboratories. In Europe however, several R&D and test facilities have been closed in the past decade. If this trend continues, the lack of experimental facilities could become a limiting factor for future nuclear activities.

For a long time, responsibility for the training and level of expertise of human resources, both on the operator side and on the side of the regulation authority is likely to remain at the national level. The strength and reliability of regulatory control heavily depends on dedicated human resources; this is generally selected by the government and the selection should be based on expertise criteria rather than political grounds. This is not generally an issue in the European countries, since the average level of education ensures quick adaptation and training in new technology.

Research and Development (R&D) in nuclear fission is important on several counts:

- To meet increasingly more demanding safety criteria with the fleet of reactors currently in operation;
- To design the next generation of nuclear reactors with a view to exceeding the performance of the existing models, in terms of safety, efficiency, economics, sustainability and security (non-proliferation);
- To maintain the EU’s technological lead and export capacity for a technology, facing competition from the US and several Far-Eastern countries;
- To attract a sufficient number of young engineers and scientists who will become tomorrow’s European pool of experts.

Research work in the fields of safety of current reactors and technologies includes: radioactive waste reduction and long-term geological disposal, acknowledging the need to improve public confidence, regarding the future exploitation of nuclear power.

These activities can only be successfully conducted over the coming decades, if education and training ensures a continuous supply of nuclear engineers and scientists, as well as the preservation of existing knowledge.

3.8 Public Acceptance

Nuclear energy will only develop within the limits of public acceptance. Since it has been a subject of controversy for a long time, members of nuclear bodies in research, industry and administration are aware they must respond to such social demands as:

- Assurance of no serious accident consequences;
- Protection of facilities against external aggression;
- Transparency and full reporting from operators;
- Established independence of a safety authority;
- Coherence with explicit national policy priorities;
- Established waste management policies;
- Public involvement; and
- In a nutshell, being trustworthy.

The latest polls suggest that more effort should be invested both by companies and by governments in these efforts, even though the percentage of declared “opponents” is decreasing in several countries.

It may be worth emphasising that from the beginning, nuclear activities have been subject to a number of rules and guidelines to maximise reliability and safety:

- ALARA (As Low As Reasonably Achievable) principle, setting the rules of behaviour for nuclear operators as the continuous search for lower health and environmental impacts under the constraint of economic and social sustainability. In fact, this is one of the first industrial implementations of the precautionary principle, but was not perceived as such when proposed in the 1950s.

- The history of continuously decreasing discharges and impacts to the environment, well documented and controlled by regulators; a clear illustration of ALARA implementation.
- International Nuclear Events Scale (INES) designed by the IAEA and the NEA to promptly communicate to the public significant safety-related events.
- WANO (World Association of Nuclear Operators) indicators of performance, setting benchmarks based on continuous monitoring and exchange between operators.
- Systematic benchmarking: not only through WANO, but also through peer safety reviews by IAEA expert groups and within other networks of operators and experts such as the ALARA network in Europe.
- Dialogue with stakeholders: within local committees on a regular basis or through specific attempts at discussion, e.g., with environmental NGOs.
- More extended corporate reporting, with indicators covering not only financial, but environmental and social performances (Corporate Social Responsibility (CSR)).

These common rules and practices should be more popularly known. The nuclear industry should also expand on its contributions to sustainable development. The concept of sustainable development has been stated as “meeting the needs of the present generation without compromising the needs of future generations”. In the energy sector, this concept can be translated into the following objectives:

- **Meeting the present needs**: the nuclear industry supplies electricity at affordable prices on a permanent and reliable basis, thus ensuring economic growth of the society. The nuclear industry minimises health and environmental impacts, by ensuring the safety of its workers and the public and to comply with social requirements. The nuclear industry also provides adequate information and involves stakeholders.

- **Without compromising future needs:** nuclear energy is minimising the consumption of non-renewable resources, minimising the long- term impacts from climate change and exposure to radioactive waste, minimising long-term land utilisation by intensive technology and site reclamation, and by developing future technological capacity through investment and R&D.

- **To what extent is this achieved and what further objectives of improvement should be set?** Answering this question requires evidence of good practice and continuous improvement, relying on facts, quantitative trends and examples as comprehensively as possible in the description, including the three dimensions of economics, environment and society.

3.9 Energy Policy Framework

The development of nuclear energy should not only rely on pure market dynamics, since several of its most attractive aspects lie in contributions to the public good:

- Energy security;
- Climate change mitigation;
- Clean atmosphere; and
- Price stability.

Long-term energy policy objectives such as these should be clearly assessed to determine the optimal mix of energy sources against such criteria. Moreover, policies affecting electricity market design itself should be stabilised and shared by all European countries to establish stable rules of the game. All of this requires for a clear European energy policy framework.

3.9.1 EU-25

In this group of countries, there is no common energy policy framework dealing directly with the structure of electricity supply. Rather, the Nice Treaty states that: "measures significantly affecting a Member State's choice between different energy sources and the general structure of its energy supply" can only be enforced if there is unanimity within the Council of European Ministers.

There are opposing positions concerning nuclear energy in the Member States, from total opposition in Austria, to decisions to build new reactors in Finland and France.

But there are some new factors, which might lead to an energy policy framework more favourable to nuclear energy:

- At the national level, several countries have expressed interest in building nuclear plants in the future (Poland, Baltic States and Czech Republic);
- The EU as a whole will probably not reach its Kyoto commitments, although very aggressive policies for the development of renewable energies have been pursued in several Member States;
- Security of supply has again become a major concern in the EU, with the sharp increase in oil and gas prices during the last two years. The increasing trend in Russian natural gas imports is viewed by some Member States as a problem if it goes too far, or if it leads to conflicts of interest among Member States;
- There is no longer a global overcapacity in electricity generation. Decommissioning of existing coal and lignite plants will accelerate around 2015, mainly due to tighter environmental regulations. These plants must be replaced in a timely fashion, since electricity demand is still increasing. Governments must become more aware that new fossil fuel plants will be unable to simultaneously fulfil the objectives of climate change mitigation and security of supply at a reasonable price, with the knowledge that carbon capture and sequestration are, at best, remote perspectives;

- In the UK, the replacement of old nuclear plants with new nuclear plants is included in the Government's Energy Review Report, July 2006. This Report also emphasises the need to develop renewable energy, to improve energy efficiency and to replace older coal-fired stations with cleaner, more efficient technologies. The two main reasons for this energy policy by the Government are the challenges of energy security and climate change.
- In his speech to the Confederation of British Industries (CBI) Annual Dinner, on 16 May 2006, the Prime Minister, Rt Hon. Tony Blair said: "*the facts are stark. By 2025, if current policy is unchanged, there will be a dramatic gap on our targets to reduce* CO_2 *emissions; we will become heavily dependent on gas; and at the same time move from being 80/90% self-reliant in gas to 80/90% dependent on foreign imports, mostly from the Middle East and Africa and Russia. These facts put the replacement of nuclear power stations, a big push on renewables and a step-change on energy efficiency, engaging both business and customers, back on the agenda with a vengeance. If we don't take these long-term decisions now, we will be committing a serious dereliction of our duty to the future of this country*". It is also important to note that this Report considers that "nuclear is a potentially economic source of electricity generation" and that "within the UK's market-based framework, it is for companies to make investments in new power stations, including investments in any new nuclear stations. Nevertheless, the Government "needs to address a number of regulatory barriers".

Extracts from a Statement by the Rt. Hon. Alistair Darling, Secretary of State for Trade and Industry (11 July 2006):

> The Government has concluded that new nuclear power stations could make a significant contribution to meeting our energy policy goals. It will be for the private sector to initiate, fund, construct and operate new nuclear plants and cover the cost of decommissioning and their full share of long-term waste management costs.
>
> The Review makes a number of proposals to address potential barriers to new build and the HSE is developing guidance for potential providers of new stations.

3.9.2 Other Western European Countries

In Switzerland, an original characteristic of the democratic system is the frequent use of referenda on various matters, including energy policy. The referendum held in 2003 indicated the majority are in favour of nuclear energy.

In Norway, nuclear energy is not on the agenda.

3.9.3 Eastern European countries

In Bulgaria, Romania and Ukraine, energy policies are clearly in favour of nuclear energy.

3.9.4 Russia

The same applies to Russia, a leading player in the field, with an important investment programme in new plants. Russia also plays a large role as an exporter of nuclear plants and fuel cycle services. There are two main reasons for the importance of this programme:

1) Until recently, Russia's electricity consumption was declining; it is now increasing sharply, in line with economic recovery. Given the present low level of electricity use in the residential and commercial sectors, this growth in electricity demand will continue in the long-run, and the need for new plants will be considerable.

2) Russia is more conscious that its gas resources, although very important, are limited. It is becoming increasingly clear that burning gas in large quantities to generate electricity (421 TWh of electricity was generated with gas in 2004, mostly in single-cycle plants) is not an effective use for these limited resources.

Recently, the Russian government approved the national programme "Development of Russian Atomic Energy Complex in 2007-2010 and up to 2015". The planned investment for 9 years is about 675 billion roubles (around 20 B€), which should support development in 4 directions:

- NPP construction (by 2015, 10 GW of commissioned new plants and another 10 GW under construction);
- Development of a front-end fuel cycle industrial base (including uranium mining capacities);
- Development of a back-end fuel cycle industrial base and preparing for NPP decommissioning;
- R&D in innovative reactor and fuel cycle technologies.

This overview of energy policies and nuclear power developments in Europe, highlights how useful a well-grounded, clear and encompassing public debate on all energy options can be, without technology exclusions. The population should be educated on energy issues to warrant shared and robust decisions in energy policy. Every policy choice implies multi-criteria analysis and arbitration between conflicting objectives (e.g., environmental protection versus competitiveness), which should be clearly stated and understood.

3.10 References

International Energy Agency, World Energy Outlook (2004).

International Atomic Energy Agency, IAEA-TECDOC-1391, Status of Advanced Light Water Reactor Designs (2004).

International Energy Agency, Nuclear Energy Agency, Projected Costs of Generating Electricity, Paris, France (OECD 2005 Update)

Nuclear Energy Agency, Decommissioning Nuclear Power Plants, Policies, Strategies and Costs (OECD 2003).

Nuclear Energy Agency, Confidence in the Long-term Safety of Deep Geological Repositories, (OECD 1999).

DGEMP-DIDEME, Coûts de reference de la production électrique, French Ministry of Economics, Finances and Industry, www.industrie.gouv.fr/energie/electric/se_ele_a10.htm, France, December 2003.

OXERA, Financing the Nuclear Option: Modelling the Costs of New Build. June 2005.

Tarjanne R, Luostarinen K., Competitiveness of the Electricity Production Alternatives (Price Level of March 2003), Lappenranta University of Technology, 2003.

AMPERE Commission, Rapport de la Commission pour l'Analyse des Modes de Production de l'Electricité et le Redéploiement des Energies (AMPERE) au Secrétariat à l'Energie et au Développement Durable, Octobre 2000, Belgium.

Dauphine University, Economies et sociétés, Tome XXXVII, N°2-3, Fév.-Mars 2003, Dauphine University, Isméa, Les presses, France.

Massachusetts Institute of Technology, The Future of Nuclear Power, an Interdisciplinary MIT study, http://web.mit.edu/nuclearpower/, 2003, USA.

Royal Academy of Engineering, The Cost of Generating Electricity, a study carried out by PB Power for the Royal Academy of Engineering, UK, 2004.

UBS Investment Research. The Future of Nuclear, www.ubs.com/investmentresearch, March 2005.

University of Chicago, The Economic Future of Nuclear Power, August 2004.

World Nuclear Association, New economics of nuclear power, 2005, http://www.uic.com.au/neweconomics.pdf

World Nuclear Association, The Global Nuclear Fuel Market, Supply and Demand 2005-2030 (2005).

Committee on Radioactive Waste Management, Managing our Radioactive Waste Safely, July 2006.

Department of Trade and Industry (U.K.), The Energy Challenge, July 2006

ANNEX 3-A

Description of Selected Technologies

Boiling Water Reactors (BWRs)

Two models of boiling water reactors, the advanced boiling water reactor (ABWR) and the ESBWR, have been developed by General Electric (GE) and Toshiba and Hitachi for the ABWR. The ABWR is a 1300 MWe power plant; the ESBWR will be 1550 Mwe.

The ABWR is the oldest: it received design certification from the US Nuclear Regulatory Committee (NRC) in 1997. Two units have been operating in Japan for several years, and four others are being built in Japan and Taiwan.

Some of its features, as described by IAEA's "Status of advanced light water reactor designs 2004" are somewhat less favourable than more recent designs. Availability: 87% or greater, core damage frequency, less than 10^{-5}/reactor year, significant release frequency, 10^{-6}/reactor year.

The ESBWR is much more recent. GE formally submitted its design certification to the US NRC on 24 August 2006. This reactor has not yet been ordered, but its design is one of the two chosen by the NuStart consortium in the US.

The ESBWR operates with natural circulation of the reactor coolant and incorporates several passive safety features. Its characteristics, as described by the IAEA document are quite favourable: availability 92% or greater, core damage frequency less than 10^{-6}/reactor-year, significant release frequency from all events (internal and external) limited to 5.10^{-8}/reactor year.

The SWR 1000, developed by AREVA NP generates 1000-1250 MWe. It was developed based on experience from existing operational plants and draws on passive safety systems.

The SWR 1000 meets all European Utility Requirements (EUR) for light water reactor (LWR) power plants, and was subjected to a preliminary assessment by the Finnish Safety Authority (STUK), thereby enabling AREVA to offer this model in response to Finland's call for bids. It incorporates passive safety equipment together with proven active safety systems.

Pressurised Water Reactors (PWRs)

The European pressurised water reactor (EPR) model is the result of the partnership between Framatome and Siemens KWU. The two companies worked together and in 2001, combined nuclear activities to create Framatome ANP, today a joint subsidiary of AREVA and Siemens. After a ten-year development phase involving EdF, the main German utilities and French and German safety authorities, the EPR has now entered its industrial completion phase, with projects underway at Olkiluoto 3 in Finland and Flamanville 3 in France. Rated thermal nuclear steam supply system (NSSS) power is 4,524 MW (standard value) and rated net electrical power up to 1,650 MWe (depending on site conditions). A net efficiency of more than 37% can be obtained.

Redundant trains of all safety systems are installed in four separate layout divisions with strict separation ensured so that common mode failure due to internal hazards, for example, can be ruled out. A four-train redundancy for the major safety systems provides flexibility in adapting the design to maintenance requirements, thus contributing to reduce the outage duration. A standard refuelling outage of less than 16 days is sufficient to perform all necessary operations: reactor cool down, fuel unloading, inspection, maintenance, refuelling, and bringing the reactor back to normal operating temperatures.

The Westinghouse AP1000 Advanced Passive Plant is a two-loop 1100 MWe PWR, with passive safety systems based on natural phenomena (gravity, natural circulation and condensation). These systems require no operator action for 72 hours after an accident, and can maintain core and containment cooling without AC power. There are 50% fewer valves, 35% fewer pumps, 50% less seismic building volume, 80% less pipe and 80% less cable in an AP1000 than in a conventional reactor, leading to lower capital and operating costs. Its modular design will reduce construction time to 36 months, from first concrete pour to fuel loading. The AP1000 obtained Final Design Approval by the US Nuclear Regulatory Commission in 2004 and it is the only Generation III + plant to have received Design Certification (December 2005). The AP1000 meets the US User Requirements document (URD) and EUR requirements. The AP1000 has been selected by the People’s Republic of China as the technology they intend to implement.

In Russia, work on nuclear plants of a new generation was launched in 1989 in the framework of the governmental programme “Environmentally Safe Energy”. In the first stage of creating a NPP of the new generation, the existing plant designs using active safety systems were modified to achieve design simplification, optimisation of thermal parameters, and more efficient use of fuel. ***V-392*** is a four-loop VVER-1000 facility with electric power of 1000-1100 MWe, equipped with horizontal steam generators. The reactor has a greater number of control elements and a system for quick injection of boron based on passive principles to back up the main shutdown system. A very important feature of the new reactor is its passive heat removal system, designed to operate in all conditions of design-basis and beyond-design-basis events and to ensure heat removal from the core in case of loss of active cooling systems or of all sources of power. The reactor is also equipped with a core flooding system to keep the core covered in loss-of-coolant accidents.

The safety of the V-392 reactor facility rests on the following:

- Improvements in the core and enhancement of inherent safety characteristics, equalisation of power distribution throughout the core volume, burnable poison incorporated in the fuel;
- New refuelling strategy that raises the plant cost-effectiveness by 5% to 7%, due to higher burnup or longer fuel life in the core, and allows reduction in the neutron flux to the reactor vessel;
- Enhanced fuel versatility;
- More efficient emergency protection system, to provide power reduction and core cooling to 100°C without boron injection into the coolant; and the
- Use of active emergency core cooling systems in normal operation, and the greater use of the role of passive systems in safety assurance, thereby reducing the requirements for rapid Emergency Core Cooling System (ECCS) action to provide core cooling in emergencies.

The design service life is 40 years. The estimated core damage frequency is 10^{-6} per reactor year; the probability of a major radioactive release $<10^{-7}$.

VVER-640 uses a four-loop reactor facility VVER-640 (V-407) of a new generation with horizontal steam generators. The power of the reactor is 1800 MWth. Fuel efficiency has been raised by 30-35% relative to modern VVER-440s. The plant is furnished with a double cylindrical containment (an inner leak-tight steel shell and an outer envelope of reinforced concrete). The inner shell is provided with filters.

The plant can operate in different climatic conditions and in seismic regions with an ultimate earthquake design-basis of magnitude 8. The plant owes its higher safety to the predominance of passive safety features for emergency core cooling and decay heat removal. The safety margins of the fuel are 10 times greater than in existing VVER-440 and VVER-1000 reactors.

VVER-640 complies with modern standards and has already been given site permission in accordance with new licensing rules adopted in 1994. On 13 October 1994, Gosatomnadzor (Russian regulator) issued permission to build three generating units at the Kola site (to replace the existing VVER-440 reactors). On 28 June 28 1995, Gosatomnadzor licensed the site of a research institute in Sosnovyi Bor for construction of a prototype VVER-640.

The design service life is 50 years.

Heavy Water Reactors (HWR)

The Pressurised Heavy Water Reactor (PHWR) CANDU system, developed by Atomic Energy of Canada Limited (AECL) is a mature technology operated or under construction in seven countries. In Europe only one CANDU 6 system has been in operation, in Romania (Unit 1 of Cernavoda NPP) since December 1996; the second is under construction on the same NPP site (Unit 2 of Cernavoda NPP) and will become commercial in 2007.

The first CANDU designs were originally predicated on optimal thermal neutron utilisation to permit the use of natural uranium as a fuel. However, the CANDU system, like all high technology products, has had to evolve quickly to meet the new requirements of the 21st century power market. The Advanced CANDU Reactor ACR-700 is derived from the CANDU 6. Its most obvious modifications are the use of slightly enriched uranium fuel combined with light water as the coolant, allowing a more compact design and a reduced heavy water inventory. The ACR-700 will retain all the characteristics of the present CANDU reactor, including high neutron economy, modular design, on-power fuelling, passive safety, and simple fuel design. These characteristics comprise a logical and systematic advance of the design through an evolutionary process. Some of these same characteristics allow the technology to be applied to a much-advanced fuelling strategy, without having to change the basic concept.

ANNEX 3-B

Full Cost of Generation: Main Results of the OECD/NEA-IEA Report (2005)

The OECD/NEA (2005) study includes seven EU countries using nuclear power: five from Western Europe and two from Eastern Europe. The common assumptions selected for the study were:

- Plant lifetime = 40 years whatever the technology;
- Average load factor = 85% whatever the technology;
- Assessments with two discount rates (D.R.) = 5% and 10%;
- Exchange rate 1 EUR = 1.14 USD.

Waste management expenses were to be included in the nuclear fuel cost; conversely, no provision was made for eventual taxation of CO_2 emissions.

At a 5% discount rate, the calculated levelised costs are in the range 2.3 - 3.1 US-cent/kWh (1.9 - 2.6 €-cent/kWh) with an average of 2.7 US-cent/kWh (2.25 €-cent/kWh).

The findings of the OECD/NEA report were.

- At a 5% discount rate, the levelised costs of nuclear electricity generation for a new build based on existing designs are usually below 3 US-cent/kWh. Nuclear is cheaper than coal and gas in all the participating countries. Investment costs represent the largest share of total levelised costs, around 50% on average, while O&M costs represent around 30% and fuel cycle costs around 20%.
- At 10% discount, levelised costs are likely to be above 3 US-cent/kWh. In eight countries, nuclear is cheaper than coal and gas, while coal is cheaper in four countries. Investment costs rise to about 70% of total nuclear cost.
- OECD experts argue that discount rates of 5 and 10% respectively embrace the range of real discount rates used in OECD countries (cf., “Projected Costs of Generating Electricity”, OECD/IEA–NEA, 2005). These findings are shown in the following Tables and Figures.

ANNEX 3-C

Generation costs (US-cent/kWh) for nuclear new build of existing designs calculated at a lifetime of 40 years, 5% discount rate, and base year 2003.

Country	Capital	O&M	Fuel	Total
France	1.4	0.6	0.5	2.5
Finland	1.6	0.6	0.5	2.7
Germany	1.5	0.9	0.5	2.9
Switzerland	1.7	0.7	0.5	2.9
Slovak Republic	1.5	1.0	0.6	3.1
Netherlands	1.9	0.9	0.8	3.6

Source: OECD 2005

ANNEX 3-D

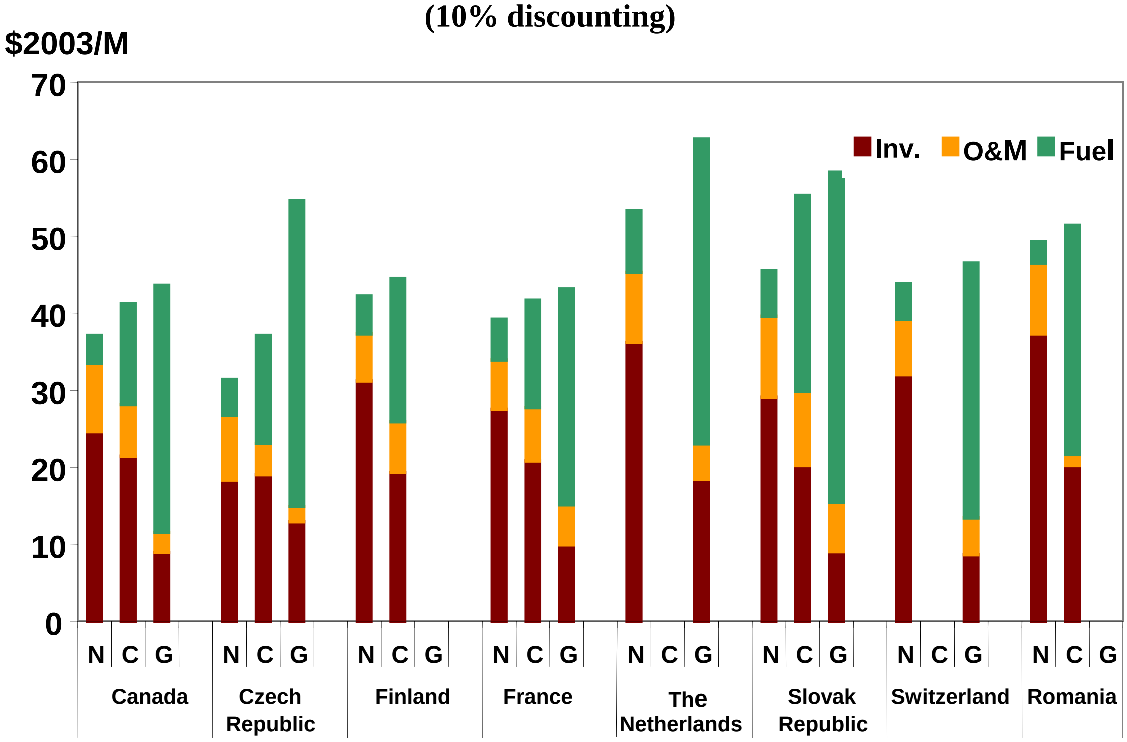
Generation costs (US-cent/kWh) for nuclear new build of existing designs calculated at a lifetime of 40 years, 10% discount rate, and base year 2003.

Country	Capital	O&M	Fuel	Total
France	2.8	0.6	0.5	3.9
Finland	3.1	0.6	0.5	4.2
Germany	2.8	0.9	0.5	4.2
Switzerland	3.2	0.7	0.5	4.4
Slovak Republic	2.9	1.0	0.6	4.5
Netherlands	3.6	0.9	0.8	5.3

Source: OECD 2005

ANNEX 3-E

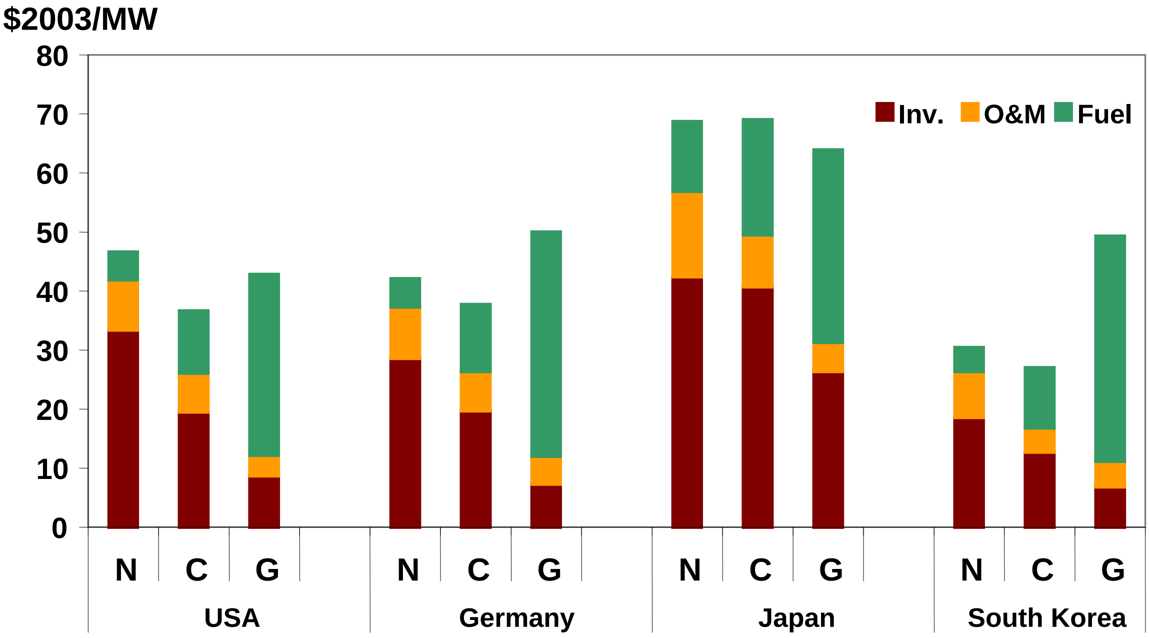
Countries where mean levelised cost of nuclear in base load is the cheapest option (10% discounting)



Source: OECD Study, 2005

ANNEX 3-F

Countries where mean levelised cost on nuclear in base load is not the cheapest option (10% discounting)



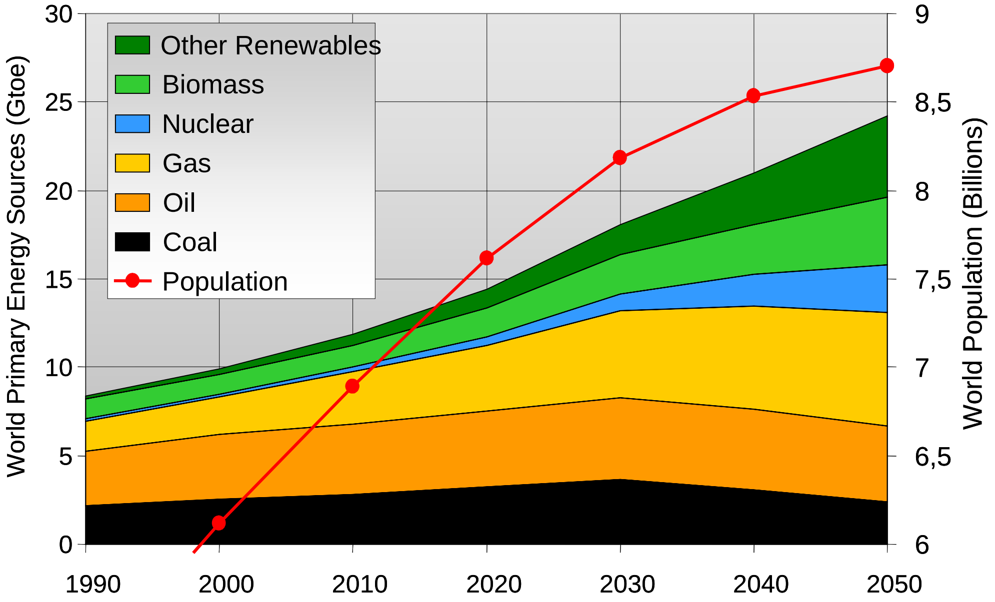
Source: OECD Study, 2005

CHAPTER 4: NUCLEAR POWER WITH NEW TECHNOLOGIES

4.1 The Stakes for Future Nuclear Energy Systems

By 2050, the world population is expected to reach about 9 billion people and energy consumption should double to about some 20 Gtoe/year. The rising awareness of fast growing world primary energy demand at the beginning of the 21st century pressured the developed nations to find ways to satisfy this demand without serious environmental damage and more recently, without massive increases in greenhouse gas (GHG) emissions, potentially responsible for unpredictable, irreversible and global climate changes. Since all energy sources are likely to be needed, one major interest is to explore and develop optimal energy mixes that satisfy requirements for energy security, generation cost, resource savings and mastery of environmental impact, under different future circumstances. Several prospective studies, such as *"Global Energy Perspectives to 2050 and Beyond"* and *"Energy to 2050 – Scenario for a Sustainable Future"* conducted by the World Energy Council (1998) [1], and the International Energy Agency (2003) [2], respectively, and the *"White Book on Nuclear Power (2001)"* by the Ministry for Atomic Energy of the Russian Federation [3], show that, even with optimistic assumptions about the potential contribution of fossil and renewable energies; nuclear energy will be needed where it can be developed safely and competitively (Figure 4.1).

Figure 4.1 – IEA scenario of energy growth for a sustainable future [2]



Source: IEA, 2004

To provide adequate and sustainable electricity in the second half of this century, future prospects of cogeneration and the need for energy products other than electricity, such as hydrogen, synthetic fuels and high temperature heat for industrial processes, also trigger renewed interest in nuclear energy. Hydrogen is already needed to produce ammonia for fertilisers and to treat heavy crude oil, an application of increasing importance in the next decades. Nuclear energy could also produce heat and/or steam to help exploit tar sands or oil shale, and produce synthetic hydrocarbons as make-up fuels for gasoline from conventional oil resources. The growing interest in a hydrogen economy and recognition of the strategic nature of hydrogen technologies in the United States (US), Europe, Japan and other countries led to the signing of a multilateral agreement of International Partnership for Hydrogen Economy (IPHE) in November 2003, in Washington DC. This paves the way for important R&D programmes on nuclear hydrogen production.

The safe operation of current power plants over the past 20 years, the increasing economic competitiveness of nuclear energy as fossil fuel prices escalate, and considerations of energy security suggest further development of nuclear energy in Asia and a possible comeback in the US and Europe. Installed capacity of nuclear power could be as high as 1500 GWe by 2050, about four times greater than current installed capacity (370 GWe). Assuming only the deployment of light water reactors (LWR) that use around 0.5% of their uranium (^{235}U mainly) over a lifetime of 60 years, this would imply a demand for about 15 million tonnes of natural uranium. This amount is comparable to estimated reserves plus speculative resources, assuming prices up to 130US$/kg [4]. Even if the situation around the middle of the century does not lead to a shortage of uranium, because of additional reserves in phosphates or sea water, rising costs of recovery will lead to price increases.

Continuing research and development (R&D) on fuel and reactor technologies of 3rd generation LWRs is needed to optimise these evolving reactors, to meet the energy service needs of the 21st century. Improving the conversion ratio of LWRs to use up to 2% of the uranium energy content is of special interest to temporarily mitigate the consequences of rising natural uranium costs, pending the anticipated deployment of fast neutron reactors in the second half of the 21st century. Fast neutron reactors with a closed fuel cycle should be able to make use of more than 80% of the energy in natural uranium by 2040 (compared to the current LWR utilisation of only 1%). Such fast neutron reactors also can greatly reduce the ultimate volumes of long-lived radioactive waste for disposal.

The recycling of spent fuel to reuse fissile and fertile materials and to burn long-lived radioactive waste (minor actinides) can reduce both the decay heat of trans-uranic fuels and long-term waste disposal requirements, by using advanced spent fuel treatment processes and trans-uranic fuel re-fabrication. Research is needed to achieve improved resistance to proliferation risks for these processes and to automate them to provide appropriate radiological protection. Cooperation on these issues is invited by the US Department of Energy (DOE) within the Global Nuclear Energy Partnership (GNEP) and is intended to develop proliferation resistant technologies to expand nuclear energy worldwide.

In summary, R&D are essential to prepare the future of nuclear energy in at least three directions:

- Securing sustainable electricity generation in the second half of the 21st century, while natural uranium prices rise and while assuring adequate control of proliferation risks associated with the front and back-end of the fuel cycle *(reprocessing and recycling)*;

- Developing the production or cogeneration of energy products other than electricity *(hydrogen, synthetic fuels, process heat for industry); and*
- Encouraging innovation to adapt 3rd generation reactors to a context of evolving reactor technology over the 21st century.

4.2 Key Technologies for Future Nuclear Energy Systems

Future nuclear energy systems such as fast neutron reactors with a closed fuel cycle, as well as high or very high temperature reactors (> 850 °C) demand innovation in materials sciences beyond those required for light water reactor (LWR) technologies. This is the reason for considering a 4th generation of nuclear systems, composed of reactors and fuel cycle plants, but unlikely for deployment before 2030.

Both the Generation IV International Forum (GIF) launched by the US-DOE in 2000 [5] (Appendix X) and the International Project on Innovative Nuclear Reactor (INPRO) [6] launched by the IAEA in September 2000, have specified key technologies needed for both candidate types of 4th generation systems:

- **Fast neutron systems with a closed fuel cycle** for sustainable nuclear energy, i.e., efficiently using natural uranium (up to 80-90%, as opposed to 0.5% with LWRs today) and minimising long-term noxious qualities and decay heat of the ultimate disposable waste;
- **Advanced spent fuel treatment processes** to optimise the nature of the ultimate waste and afford increased resistance to proliferation risks; and
- **High or very high temperature nuclear systems** for energy applications other than electricity production such as hydrogen, synthetic fuels, and process heat for industry.

4.2.1 Sustainable Nuclear Energy

Candidate systems for sustainable nuclear energy mainly consist of:

- Sodium fast reactors (SFR) as the more mature technology; and
- Gas or lead (or lead-bismuth) fast reactors (GFR or LFR) as second candidate technologies.

Supercritical water-cooled reactors with fast neutrons and molten salt reactors with a thorium fuel cycle may also be considered as prospective technologies. However, at the present stage, their potential for industrial applications needs to be assessed more precisely, through an appropriate development plan.

It is important for Europe, to maintain at least a two-track approach to develop a fast reactor for industrial deployment in the second half of the century. These include:

- Seeking innovations to make significant progress on sodium cooled fast reactors as feedback from experience with prototype operations (Phenix, Superphenix, PFR, BN600 in Europe);

- Revisiting gas or lead-alloy cooled fast reactors as potential alternative technologies to sodium, even though the innovative nature of this reactor type requires building an experimental reactor before considering a prototype, thus imposing a longer lead-time and greater development effort.

The recommendation to work on at least two fast reactor technologies is intended:

- To make the process of selecting one technology for industrial deployment by 2040 more robust, due to known assets and residual difficulties of sodium cooled reactors;
- To propose a choice of technology based on performance and to facilitate public acceptance; and
- To account for probable marketing opportunities for more than a single technology, given the potential and diverse worldwide needs.

Sodium Cooled Fast Reactor (SFR)

The Sodium cooled Fast Reactor (SFR) is the reference technology, and may be considered for industrial deployment in the medium-term since Europe, in cooperation with Japan, Russia and the US, has acquired important expertise in this reactor type. However, innovations are needed for a Generation IV SFR to compete with Generation III LWRs in economics and safety. This will require systems simplification to reduce investment costs, enhanced safety with improved prevention and management of severe accidents, improved operability (fuel handling, maintenance and repair) to achieve high capacity factors, and advanced closed fuel cycles with multiple recycling of actinides offering appropriate resistance to proliferation and optimized waste forms.

Given the maturity of the technology, the next facility built in Europe will be a prototype reactor with a power conversion system of 300 to 600 Mwe, to demonstrate innovations selected to upgrade SFR performance and to open the way to a “first of a kind” (FOAK) commercial reactor.

Gas cooled Fast Reactor (GFR)

The helium cooled fast reactor is an innovative nuclear system, with attractive features such as a chemically inert and optically transparent coolant, as well as a quasi-decoupling of the reactor physics from the state of the coolant. Other advantages of the GFR relate to its promise as a very/high temperature reactor (V/HTR) capable of producing hydrogen, synthetic fuels and process heat. On the downside, since gas is a poorer coolant than liquid metals, key aspects demonstrating the viability of the GFR, include development of a refractory and dense fuel, and robust management of accidental transients, especially cooling accidents.

Lead cooled Fast Reactor (LFR)

Lead and lead alloys *(lead bismuth eutectic)* are considered an alternative to sodium, as a liquid metal coolant for fast reactors. Russia has some experience in building and operating small lead cooled power reactors in the 100 MWth range; several Russian organisations are participating in a project to develop a lead cooled reactor BREST-300 (300 MWe). Lead cooled systems have the advantage of operating primary systems at atmospheric pressure and allowing in-vessel steam generator units and the suppression of intermediate systems. Current R&D on this reactor system addresses critical issues associated with using lead as a coolant for reactors in the power range of 1 GWe, such as weight, corrosion and conditions of in-service inspection, maintenance and repair. Recent work on lead alloy cooled spallation targets for accelerator driven transmutation systems, led to the development of competence and laboratory scale experiments (mainly lead alloy corrosion loops) in Italy and other European countries.

Work on more prospective reactor types such as supercritical water reactors (SCWR) and molten salt reactor (MSR) or molten salt coolant is so far limited, to assessing feasibility and performance issues and advancing special basic key technologies.

The Path forward

As a result of a presidential decision at the beginning of 2006, France will study and build a prototype demonstration sodium fast reactor, to be put into service around 2020. This project welcomes international partnerships and urges the determination of major design features of the prototype by 2012. In parallel, Russia is proceeding with the construction of BN-800, an 800 MWe evolution of the operating BN-600 reactor. Also in parallel, national and European R&D programmes, to assess the viability and performance of gas and lead cooled reactors are being encouraged, again with an opportunity for broad international collaboration. These efforts could lead to selection of a second technology for fast reactors around 2010-2012 and to decisions on the design features of the first experimental facility in the range of 50-100 MWth to be built in Europe. The project could ultimately develop as a joint undertaking between several European countries. The roadmap for selecting a second fast neutron reactor and its implementation could be discussed within the framework of a “European Sustainable Nuclear Fission Technology Platform,” in preparation for the 7th European R&D Framework Programme (2007-2011).

4.2.2 Very/High Temperature Nuclear Process Heat and Hydrogen Production

The production of hydrogen or synthetic hydrocarbon fuels, and generation of high temperature heat for industrial processes constitute another direction of R&D to extend applications of nuclear energy beyond the generation of electricity. The very/high temperature reactor (VHTR) is derived from high temperature reactor (HTR) prototypes operating in Europe and in the US between 1960 and 1980.

Since 1999, active cooperation within the European R&D Framework Programme complements the multilateral cooperation on the VHTR within the Generation IV Forum, principally with France, the US, Japan and South Korea. The next step should be the design and construction of a prototype of the VHTR. Current plans in this respect, exist in South Africa (Pebble Bed Modular Reactor - PBMR) and the US (New Generation Nuclear Plants), in which Europeans could seek partnership. Comparable initiatives in Europe, include both the projects ANTARES of AREVA and GT-MHR of OKBM. Building a prototype in Europe, requires a strong expression of interest from vendors and potential customers of VHTR energy products. This could be conceived as a joint undertaking with public and private co-funding.

4.3 Plea for Strong Involvement of Europe in 4th Generation Nuclear Systems

4.3.1 Stakes of 4th Generation Nuclear Systems for Europe

With an installed capacity of 131 GWe and a 35% share of electricity production, nuclear energy is already important for the EU. It is even more important within the

European region of the WEC that includes Russia, another large nuclear country. A brief and partial survey of current national programmes in WEC Europe is presented in Appendix 4-B. Beyond sharing national experience in maintaining high level safety standards, extending plant lifetimes, managing spent fuel and radioactive waste, and renewing existing operating reactors by 3rd generation nuclear plants, Europe should actively participate in longer-term international efforts, in order to prepare for the future.

There are several reasons for this:

- It builds on experience acquired on prototypes of sodium cooled fast reactors and high temperature reactors;
- It allows Europe to develop a vision of future nuclear energy needs and associated key technologies, and to actively participate in specifying criteria for future nuclear energy systems of potential interest in Europe;
- An organisation to make plans and to actively develop such technologies could realise experimental or prototype reactors in Europe;
- It would assure fair and balanced conditions of collaboration with major partners such as the US, Japan and possibly others in the future, such as China, and benefit from broader international collaboration to share the costs of R&D and prototype reactors; and
- It would support the current leadership of the European nuclear industries on the international scene and in acquiring intellectual property rights to key technologies to be commercialised in a few decades.

4.3.2 Status of 4th Generation Nuclear Systems in the European R&D Programme

Diverging national visions of nuclear energy in Europe has limited work on future fission systems, although there is a visible and reasonably funded R&D programme on future nuclear fission systems within the Euratom R&D framework programme (Annex 3-C). The 6th R&D Framework Programme (FP6, 2002-2006) was allocated a global budget of 824 M€ for fusion and 528 M€ for fission-related R&D (including 319 M€ for the Joint Research Centre). Most of this budget is dedicated to cooperative R&D on LWR safety, waste management and radioprotection that contributes to optimising the operation of power reactors in Europe. Less than 20 M€, less than 4 M€/year, was allocated to “Innovative concepts to generate energy.” Within this budget, a continuing R&D programme on VHTR processes and technologies has been co-funded (50% by the European Commission) at a level of 2 M€/year since 1999, whereas point design studies and focused R&D work on gas fast reactor (GFR) and supercritical water reactor (SCWR) are currently co-funded at 0.7-1.0 M€/year. The decision was taken in 2006, to support preliminary studies on the lead fast reactor (LFR) at a comparable level (1.2 M€/year) and to include activities on sodium fast reactor (SFR) and molten salt reactor (MSR) from 2007 onwards.

Strengthening the effort in Europe on future nuclear fission systems is in full agreement with Euratom formally joining the Generation IV Forum on 11 May 2006 and with the orientation of both “Green Books” issued by the European Commission in 2000 and 2006 for sustainable energy development in Europe [7, 8]. Initiatives in this sense are all urgently needed in the 7th R&D Framework Programme (2007-2011). The proposed budget of the 7th Framework Programme currently amounts to 1947 M€ for fusion and 804 M€ for fission (including 517 M€ for the Joint Research Centre).

Management of Competences in Nuclear Fission

So far, the European R&D Framework Programme, together with national initiatives, has been successful in preserving competence in the nuclear field through a network of excellence, cooperative actions and by promoting the European dimension of education in nuclear engineering. Future nuclear energy systems will require all aspects of expertise involved in the design, technology development and safety demonstrations for LWRs, nuclear fuels and fuel cycle processes including: design and safety studies, fuel, materials and component technology and waste management processes.

The search for breakthroughs beyond LWR technologies, such as very high temperature and/or fast neutron systems with full actinide recycle, will require additional and non-nuclear-specific skills in materials science, very high temperature materials and components (composite C/C and ceramics), separation chemistry, and thermo-chemical and electrochemical processes for water splitting and hydrogen production.

Other competence is required, either for prospective studies (uranium resources, hydrogen market) or assessments in economics, safety or proliferation resistance. Updating assessment methods may be effected nationally, through collaboration or through participation in International Project on Innovative Nuclear Reactors (INPRO) and/or corresponding methodological groups of the Generation IV Forum *(Economics modelling, Risk and safety, Proliferation resistance and Physical protection).* The development of networks of experts in these fields in Europe may be considered.

All fields of nuclear expertise need continuous support from the existing instruments in FP6 including networks of excellence *(e.g., ACTINET, SARNET)* and integrated projects *(e.g., EUROPART, EUROTRANS, PERFECT, NURESIM).* The need in FP7 for an additional instrument dedicated to nuclear fuel deserves further consideration. Access to non nuclear-specific expertise calls for continued effective connections and support for all these sources beyond the Euratom FP7.

Renewal and Evolution of Large R&D Facilities

Materials testing reactors and hot laboratories are essential R&D infrastructures to explore innovative research on fuels and fuel cycles, key technologies for 4th generation reactors:

- HFR, Osiris, LWR-15 and Jules Horowitz Reactor (JHR) in 2014;
- ITU, Atalante, FzK, SCK, Actinet core group facilities;
- BOR-60, Phenix.

Sizeable non-nuclear facilities are also needed to resume R&D on high temperature gas-cooled reactors, such as the particle fuel laboratory scale fabrication line, test benches for high temperature helium system technology (850, 950 °C and above) and experimental loops in the 1 to 10 MW range for component mock-up tests. France is engaged in re-establishing such a basic R&D capability. Equipment costs for this effort on a European or a broader international basis are estimated to be about 100-300 M€. The cost for R&D equipment to resume the industrial development of sodium-cooled fast reactors is about the same.

The decision to build a prototype of 4th generation fast neutron reactors in France by 2020, is important for Europe to remain credibly involved in R&D on fast neutron systems after Phenix is shut-down in 2009. Other European countries, and possibly other international partners may decide to develop experimental or prototype reactors of other Generation IV systems of specific interest, with invited external participation. Even though the costs of such facilities range from 0.5 to 2 billion Euros (B€), the prospect of such prototypes does not appear excessively ambitious, in comparison with the number of experimental and prototype reactors operating in Europe in the 1980s:

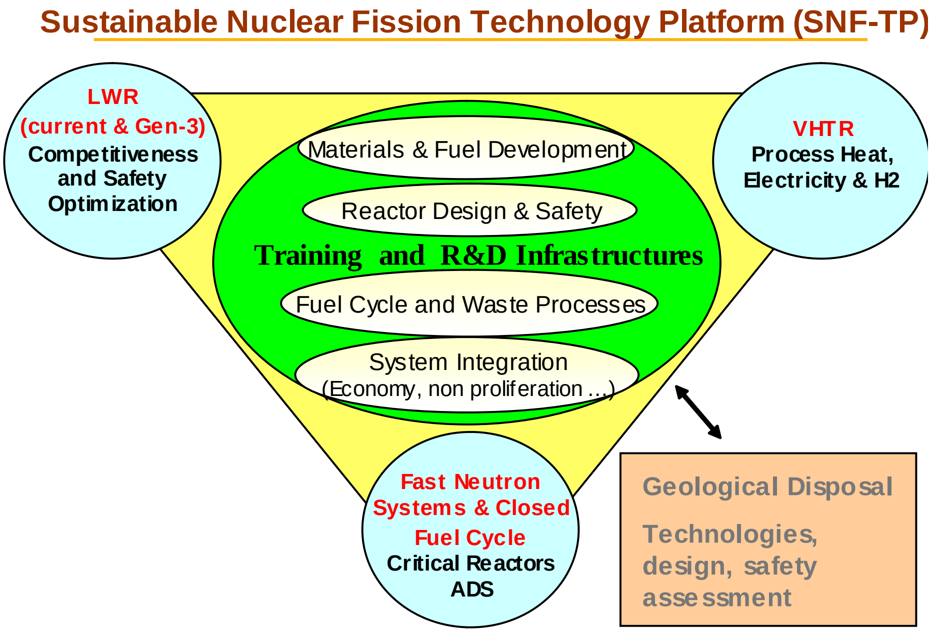
- Sodium cooled fast reactors (SCFRs):
  - The experimental reactor KNK II (17 MWe) in Germany (1978-1991)
  - The prototypes Phenix (250 MWe) in France (1973-2009), PFR (234 MWe) in the United Kingdom (1975-1994), BN600 in Russia (1980 onwards);

- High temperature reactors (HTRs):
  - The experimental reactors Dragon (1964-1975) in the UK and AVR (13 MWe) in Germany;
  - The prototype THTR (300 MWe) in Germany (1983-1989).

4.3.3 Towards a "Sustainable Nuclear Fission Technology Platform"

One of the major initiatives to integrate and strengthen R&D work on future nuclear energy systems in Europe is the proposal to organise fission-oriented R&D work in the European Union into *a* ***"Sustainable Nuclear Fission Technology Platform"*** (Figure 4.2). This is intended to address strategic R&D for European policy makers and industrial projects in the medium-term such as LWR safe operation and life extension, fast neutron reactors with a closed fuel cycle, and high temperature reactors for co-generation.

Figure 4.2 – Goals and components of the "Sustainable Nuclear Fission" Technology Platform



A R&D organisation on nuclear fission in Europe would help:

- Direct R&D towards strategic goals;
- Identify large research equipment for this research, in order to plan for investment or refurbishing consistent with the scale of Europe; and also,
- Prepare decisions to realise and operate prototypes of 4th generation reactors within the framework of joint ventures.

It would also facilitate developing synergistic R&D for fusion systems, already organised internationally.

An appropriate level of R&D funding for 4th generation systems in Europe, should be comparable to the US and Japan in the same area, currently 300 MUS$/year exclusive of investments in experimental and prototype reactors. At stake is the preservation of the advance made by the European nuclear industry in the world, preparing the deployment of sustainable fast neutron systems with advanced recycling modes in Europe by 2040, and promoting the development of key technologies for non-electricity applications of nuclear energy.

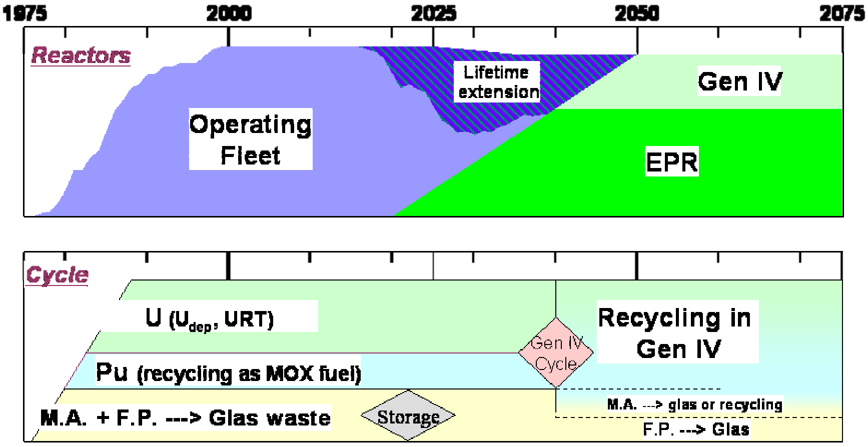
4.4 Prepare the Transition from Light Water Reactors to Fast Reactors

The path for Europe towards a closed fuel cycle depends on political, technical and financial contingencies. Indeed, such an evolution implies:

- Integration within the broader worldwide policy of safeguarding and proliferation resistance;
- The renewal and addition of new plants for processing spent fuel and re-fabricating fuel to be recycled with advanced processes; and
- A funding process for the new investments required, especially in fuel cycle plants.

Figure 4.3 illustrates the transition from current reactors and a spent fuel treatment plant in France to Generation IV technologies around 2040. It shows how deployment of a progressive separation and recycling strategy allows the technical capabilities of fast neutron reactors and advanced recycling modes with a co-management of actinides to be implemented around 2040. This strategy is flexible enough to be adapted to the time line and type of fast neutron systems to be developed. Furthermore, it creates the possibility (if ever compatible with the technical and economical optimisation of the fuel cycle) of an integral recycling of actinides (Figure 5) capable of drastically reducing long-term potential radio toxicity and decay heat of the ultimate waste (Figure 6), and making the fuel cycle more resistant to proliferation. Implementation of such technology would mean a basic solution of the final waste disposal on the principle of radiation equivalente [3].

Figure 4.3 – Scenario of Renewal of French Nuclear Plants and Fuel Cycle Plants



2040 – Deployment of Fast Neutron Systems (SFR or GFR)
2040 – Renewed spent fuel treatment plant at La Hague (grouped actinide extraction)

Figure 4.4 – Integral recycling of actinides (U-Pu + minor actinides) U_{nat} or U_{dep} as make-up fuel

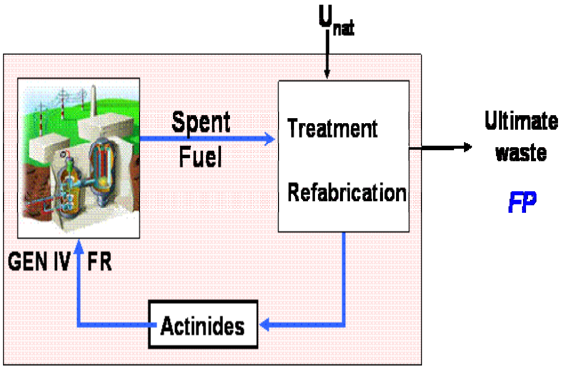
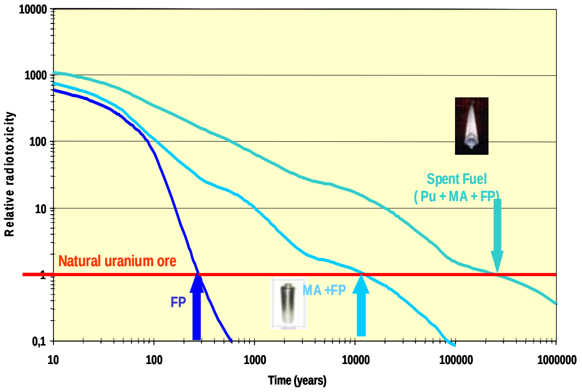


Figure 4.5 – Evolution of radiotoxicity of ultimate waste for direct disposal, recycling of U-Pu only, and integral recycling of actinides



4.5 From Fission to Fusion

A completely different approach to nuclear energy is that related to fusion using two isotopes of hydrogen as fuel: deuterium and tritium. The first, for which availability is practically unlimited, is a natural isotope (0.016% of natural hydrogen), while the second is produced in existing fission reactors or could be produced from lithium within the fusion machine itself.

International efforts on nuclear fusion are concentrated in ITER (International Thermonuclear Experimental Reactor), a project involving China, the EU and Switzerland (represented by Euratom), India, Japan, the Republic of Korea, the Russian Federation and the US, under the auspices of the IAEA.

ITER is the experimental step between today's studies of plasma physics and tomorrow's electricity-producing fusion power plants. It consists of a *tokamak* operated with deuterium and tritium at over 100 million degrees that will produce 500 MW_{th} of fusion power. The site of Cadarache (southern France) proposed by the EU was finally retained in June 2005, to host the experimental reactor. The plant will be in service in 2016.

Electricity production with fusion reactors is not anticipated in the foreseeable future in current energy plans. However, operation of ITER in 2016 and of the fusion demonstration reactor (DEMO) around 2035, evince common R&D pathways with advanced fission reactors. These include the active participation of nuclear research and industrial organisations in synergistic fusion/fission programmes on structural materials exposed to fast neutron damage, tritium breeding blanket design studies and technologies, power conversion, etc. Additional synergies relate to safety analyses and demonstrations for an experimental reactor such as ITER, to be derived from practices used for fission reactors.

In return, current R&D on 4th generation systems could benefit from those developments in low activation structural materials (especially ceramic and composite materials), that led to experiments of common interest for fusion and advanced fission reactors (especially irradiation tests in materials testing reactors). Such synergies should further develop as design features and technologies of the next ITER step are addressed (2035). The DEMO reactor is likely to be dedicated to demonstrating full tritium breeding (0.5 kg T/day for 1 GWe), since deuterium/tritium fusion reactors would be the first nuclear systems without a substitute fuel. Producing the initial tritium load for such a DEMO reactor and its successors, most likely in fission reactors, is expected to be the subject of additional synergies between future fusion and fission reactors.

A first generation of viable industrial deuterium/tritium fusion reactors is not expected before the last decades of the 21st century. A second generation of deuterium/tritium fusion reactors with enhanced plasma performance and successors that afford deuterium/deuterium fusion, will open the prospect of quasi-inexhaustible fusible resources (deuterium from sea water) with the ultimate waste limited to short and medium-lived activated reactor structural materials.

4.6 Future Prospects

The 4th generation nuclear energy systems support multiple goals; they should contribute to the mix of sustainable energy technologies that satisfy fast growing energy demand worldwide, with attributes for husbanding uranium resources, minimal production of long-lived radioactive waste, and production of products other than electricity such as hydrogen and synthetic hydrocarbon, or process heat for industry.

These fast neutron and high temperature reactors will require breakthroughs beyond 2nd and 3rd generation light water reactors (hence recognition of the switch to a new generation). They pose real technological challenges for nuclear fuels, systems materials and technology, spent fuel treatment processes and non-conventional applications. Their application in recycling spent fuel for efficient use of the uranium and burning long-lived radioactive waste, leads to consideration of these 4th generation reactors as “nuclear systems” consisting of reactor, fuel and fuel cycle, optimised as a whole.

Such technology challenges require cooperation among European research partners (National Laboratories, Universities and other research organisations) and industrial partners on corresponding R&D objectives. They also require development through international cooperation, to share the cost of innovation, experimental reactors and prototypes in Europe.

Optimising regional or global R&D also provides maximal benefit from synergistic R&D areas between advanced nuclear fission systems and experimental fusion reactors, such as design methods, safety analyses, structural materials and other technological aspects of nuclear systems.

Securing sustainable electricity generation in the second half of the century, suggests the need for possible deployment of at least one type of fast neutron reactor in Europe around 2040. This in turn suggests work along two complementary lines of research: (1) innovation to develop a new generation of sodium cooled reactors, already a mature technology, and (2) diversifying risks and market opportunities by developing at least one other reactor type such as the gas cooled fast reactor with properties inverse to sodium cooled systems or lead cooled fast reactors. The French decision to build a sodium cooled fast reactor prototype by 2020 as a successor to Phenix, could permit a comparative evaluation of the merits of alternative fast reactor types to select a second technology and build an experimental test reactor in another European country. With a core outlet temperature of at least 850°C, the gas fast reactor concept could also represent a nuclear technology useful for high temperature applications.

This stresses the need to fully integrate R&D work on future nuclear energy systems at the European level. This makes sense, in view of the important share of nuclear electricity in Europe (32%) and of the fact that Euratom affiliated countries joined the Generation IV International Forum in May 2006 (Russia together with China will soon do the same in 2007). Even though some European countries still maintain a nuclear moratorium, the preparation of the 7th European R&D Framework Programme (2007-2011) offers prospects for strengthening work in this field. This could increase exchanges with the Generation IV International Forum, an essential condition to achieve balanced cooperation with major nuclear partners such as the US and Japan, which spend about 300 MUS$/year each on future nuclear systems, and also with Russia and China.

Last but not least, another goal for European stakeholders of nuclear research and industry, is to become sufficiently involved in international R&D on future nuclear energy systems to benefit from past experience in precursor reactors of Generation IV technologies (principally sodium fast and high temperature reactors), to keep current with advances in technologies such as sodium cooled fast reactors and fuel cycle processes, and ultimately to become involved in development of standards and commercial technologies strategy for Europe and international markets.

Overcoming the current limitations of the European R&D Framework Programme on Fission and maximising European contributions to international R&D on advanced nuclear technologies, requires an integrated organisation gathering research laboratories and industry. It is essential to identify and set strategic priorities on R&D needs and necessary competence, to define needs and elaborate plans for new large experimental facilities such as material testing reactors, hot laboratories, large experimental loops, and to take decisions for the construction of experimental or prototype reactors within the joint undertakings.

Organising R&D on nuclear fission in Europe along these lines would not only help R&D towards strategic goals and make Europe a major partner of international collaboration, but would also increase the European potential to profit from building and operating prototypes of 4th generation reactors. Such a strategy would offer the best prospects for European stakeholders in nuclear energy to preserve their current leadership.

4.7 References

[1] **Global Energy Perspectives to 2050 and beyond (1998)** – Report of the World Energy Council & International Institute for Applied Systems Analysis – Cambridge University Press, UK.

[2] **Energy to 2050 – Scenario for a Sustainable Future (2003)** – International Energy Agency (IEA/OECD) Paris, France.

[3] **White Book of Nuclear Power (2001)** – Ministry for Atomic Energy of the Russian Federation.

[4] **Uranium 2005: Resources, Production and Demand (2006)**, a joint report by the OECD/NEA and the IAEA Nuclear Energy Agency http://www.nea.fr

[5] **A Technology Roadmap for Generation IV Nuclear Energy Systems** *(Dec. 2002)* – GIF-002-00 – Issued by the U.S.DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum - http://gif.inel.gov/roadmap/.

[6] **IAEA International Project on Innovative Nuclear Reactor (INPRO) –** Final report of phase 1 (2006).

[7] **Towards a European Strategy of Energy Security** *(Nov. 2000)* – COM (2000) 769 – European Commission.

[8] **A safe, competitive and sustainable energy for Europe** *(March 2006)* – COM (2006) XXX – European Commission.

[9] **European Long Term Vision for the Nuclear Energy and the recommended R&D Support** – Report of May 2004 – Michelangelo Network (Micanet).

ANNEX 4-A

The Generation IV International Forum (GIF)

The Generation IV International Forum (GIF) was set up by the US Department of Energy (DOE) in 2000, to identify key technologies for nuclear energy systems after 2030, and to organise the development of such technologies in a framework of multilateral cooperation. Current participants in the Forum include two non-active members *(Argentina and Brazil)*, and 9 active members *(Canada, France, Japan, South Africa, Republic of South Korea, Switzerland, the UK, the US and Euratom affiliated countries as a single entity)*. Russia and China will join the Forum in 2007. During the first phase of activity (2000-2002) involving around one hundred international experts (about 20 were from European countries), the Generation IV International Forum conducted a Technology Roadmap for Generation IV Nuclear Energy Systems that led to the selection of key technologies for nuclear energy by 2030 and beyond [5]. This Technology Roadmap initially maintains that fuel recycling in fast reactors is essential to reuse fertile and fissile materials (uranium and plutonium) to produce energy. Further, it emphasises the assets of an integral recycling of spent fuel, that would also manage minor actinides (neptunium, americium, curium) bear the main share of long-term radiotoxicity and decay heat.

Six nuclear energy systems were selected (Figure 4.A1.1) based on key technologies, retained to materialise significant progress over Generation III LWRs, in terms of:

- ***Sustainability*** *(resource utilisation; waste minimisation);*
- ***Safety and reliability*** *(operational safety and reliability, core damage, offsite emergency response);*
- ***Economics*** *(lifecycle cost, risk to capital); and*
- ***Proliferation resistance.***

Additional criteria regarding physical protection and malevolence were qualitatively. For such topics, as well as economic modelling, refinements of qualitative assessments are currently being sought through codified assessment methods being developed by crosscutting working groups of the Forum.

Six selected nuclear systems are intended to pave the way to the future of nuclear energy:

- **SFR** (Sodium-cooled Fast Reactor System) with a closed fuel cycle;
- **GFR** (Gas-cooled Fast Reactor System) with a closed fuel cycle;
- **VHTR** (Very High Temperature Reactor System): a helium-cooled thermal neutron reactor dedicated to hydrogen production with operating temperatures above 950°C and a target of 1000°C. At first, the VHTR is considered without spent fuel recycling;
- **SCWR** (Supercritical Water-cooled Reactor system) with thermal neutrons or fast neutrons and a closed fuel cycle;
- **LFR** (Lead-cooled Fast Reactor System) with a closed fuel cycle; and
- **MSR** (Molten Salt Reactor System) with a closed thorium-uranium closed fuel cycle.

The costs of developing such new reactor types typically, and on average, amount to 1 BUS$ of R&D and 1-2 BUS$ for a demonstration plant. Each of the above systems is the subject of a System Research Plan that describes the R&D needed to resolve key feasibility issues and to confirm its performance. For each nuclear system, this R&D plan addresses a number of projects dealing typically with computational methods, fuel, structural materials and power conversion systems. Fuel cycle issues are being addressed in two specific projects: one dedicated to fuel-specific front-end and back-end processes (dissolution and re-fabrication), and one on sensitive topics such as separation and conversion. An international demonstration of global actinide management involving the CEA hot laboratory Atalante, the spent fuel processing plant of La Hague and the sodium fast reactor Monju is currently being negotiated between Japan, the US and France as a R&D project for the sodium fast reactor.

Figure 4.A1.2 shows the three levels of organisation of the Forum:

- The ***Policy Group*** supervises all systems R&D work and assessment studies, together with maintaining relations with a Senior Industry Advisory Panel and representatives from GIF countries' safety authorities;
- The ***System Steering Committees*** steers all R&D projects related to its particular system; and
- The ***Project Management Boards*** manage R&D projects in specific technical areas *(integration, fuel, materials, system technology, power conversion).*

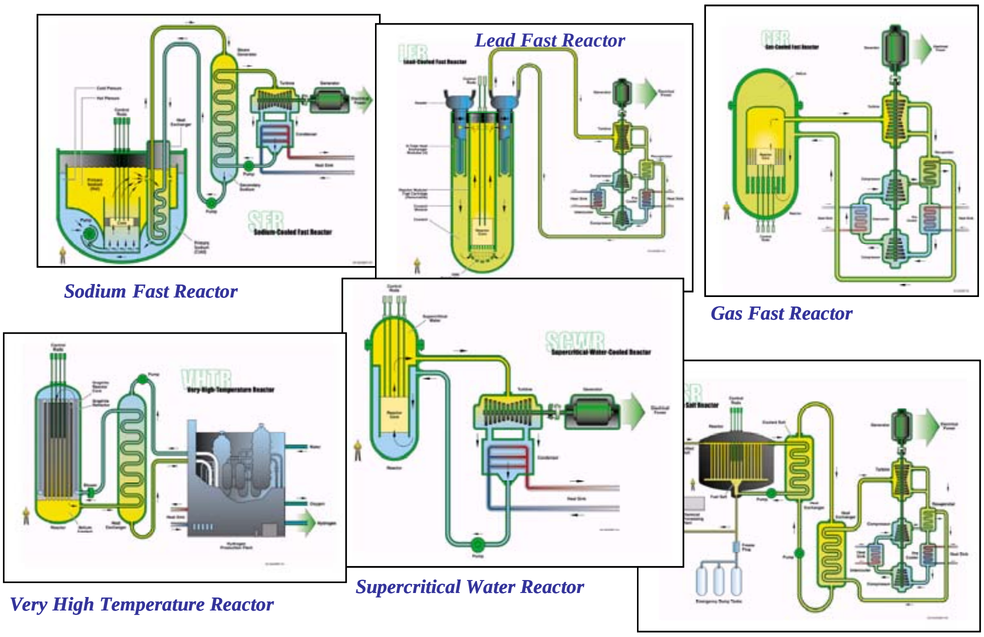
The signature of an intergovernmental agreement on 28 February 2005 marked the entry of the GIF into the phase of multilateral collaboration, to develop key technologies for the feasibility and the performance of the six selected nuclear systems. Other steps such as the signature of a cooperation agreement specific to the sodium fast reactor (SFR) on 15 February 2006 and to the very/high temperature reactor (VHTR) and gas cooled fast reactor (GFR) arrangements on 30 November 2006 resulted in the organisation and the legal framework to launch collaboration on SFR, VHTR and GFR systems in 2007. This collaboration on R&D will also aspire to trigger the interest of industrial partners and to form consortia to support development of these new reactor types, and the building of prototypes around 2020. European partners of the Generation Forum (Euratom, France, the UK and Switzerland) have tried to shape legal arrangements, so that collaboration within the GIF is fair and attractive for industrial partners, especially regarding recognition and management of intellectual property generated by the collaboration or provided in support.

The interest in the six selected Generation IV systems is, as follows:

- The ***Sodium-cooled Fast Reactor (SFR)*** currently benefits from the strong support of Japan and significant contributions from the US through the GNEP initiative, France and the Republic of Korea;
- The ***Gas-cooled Fast Reactor (GFR)*** is actively supported by France, as another fast neutron technology to be considered, as an alternative to sodium and for its potential for higher temperature applications. Japan, the US, Euratom and Switzerland contribute to conceptual studies as well, to fuel and core material developments.

- The ***Very High Temperature Reactor (VHTR)*** (>950°C) is seen as an enabling technology for the production of hydrogen or process heat for other industrial applications. It currently benefits from major support in the US and Japan (which operates the experimental reactor HTTR), a significant contribution from France, and modest contributions by the other active partners of the Forum. At least five of the partners for the VHTR have medium-term projects of precursor systems of the same type: Pebble Bed Modular Reactor (PBMR) in South Africa (400 MWth in 2012), GT-MHR/NGNP in the US (400-600 MWth in 2021) dedicated to demonstrations of nuclear hydrogen production, GT-HTR-300 in Japan (600 MWth) that operates the experimental reactor HTTR (30 MWth, 950°C), ANTARES in France (600 MWth, 850-1000°C) with plans for a prototype around 2020, and NHDD in the Republic of South Korea (600 MWth after 2020) for the production of hydrogen.
- The ***Supercritical Water-cooled Reactor (SWR)*** benefits from the major support of Canada, which sees this concept as an extension of the pressure tube technology developed for the Candu reactors. It also receives modest contributions from Japan, Euratom, France and the Republic of South Korea.
- The ***Lead-cooled Fast Reactor (LFR)*** is above all considered by the US as a secure source of power in the range of 100 MWe (“nuclear battery”).
- ***Molten Salt Reactors (MSR)*** and derivative technologies are considered by Euratom, France and the US as having potential for a thorium fuel cycle, and molten salts as being a potential coolant or heat carrier between a nuclear heat source and distant applications (hydrogen production).

Figure 4.A1.1 –The six Nuclear Energy Systems selected within the Generation IV International Forum



Sodium Fast Reactor

Lead Fast Reactor

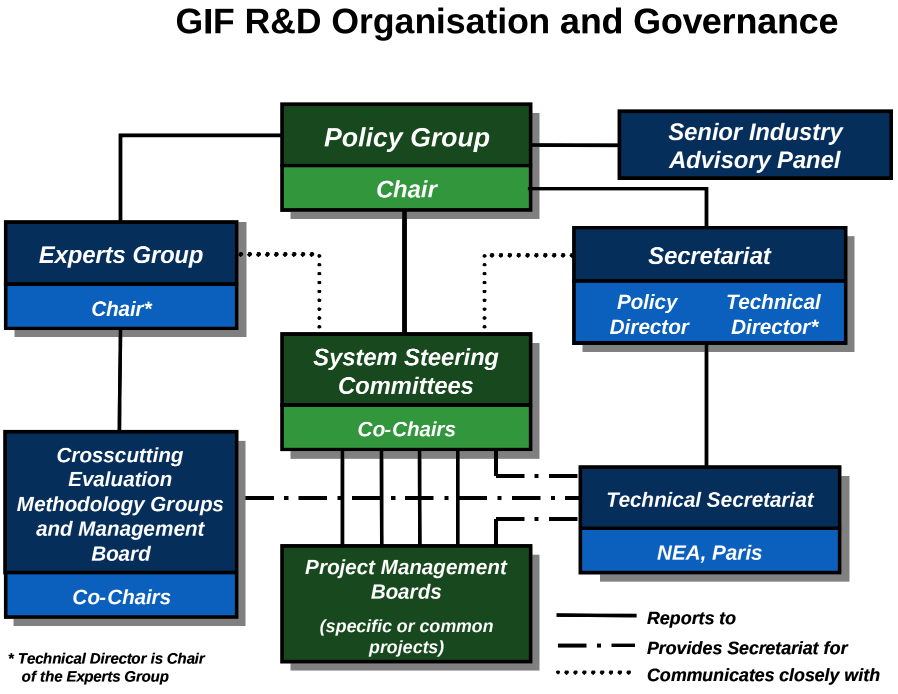
Gas Fast Reactor

Very High Temperature Reactor

Supercritical Water Reactor

Molten Salt Reactor

Figure 4.A1.2 – R&D Organisation and Governance of the Generation IV International Forum



Source: Generation IV International Forum (http://gif.inel.gov/roadmap/)

ANNEX 4-B

Brief Survey of National Programmes

Belgium (B) is actively involved in R&D on ADS as transmutation dedicated systems. Synergies with this research area have also led SCK, to develop some interest in lead-cooled fast reactors (LFR).

Czech Republic (CZ) contributed to R&D on LMFBR from 1970 to 1988. It also participated in R&D on supercritical water reactors and molten salt reactors in FP5 (HPLWR and MOST). Specific expertise on molten salt originates from collaboration with Russia on pyroprocessing. The interest of the Nuclear Research Institute of Rez and of the Technical University is primarily directed in studies and experimentation with molten salt systems dedicated to transmutation, including dry reprocessing of TRU fuel and MSR fuel salt clean up. These activities are part of a national R&D programme on "Long-Term Energy Concept" supported by the government, which also supports participation of Czech institutes in the Generation IV International Forum.

France (F) is a member of the Generation IV International Forum (GIF).
The French R&D programme on future nuclear systems was formally approved by the Ministers of Research and Industry in March 2005 along the following lines:

- A redundant approach to fast neutron systems through parallel studies and development of the sodium fast reactor (SFR) and gas cooled fast reactor (GFR), as well as advanced fuel cycle processes for global management of actinides (including minor actinides). At stake is development of a common vision of the potential of the GFR, as another approach to fast neutron systems and a sustainable version of the very/high temperature reactor (VHTR);
- Development of very / high temperature nuclear technologies in close collaboration with industrial partners for the cogeneration of hydrogen and hydrocarbon fuels, as well as for process heat applications to be identified;
- Maintaining R&D on innovative concepts and technologies for light water reactor (LWR) fuel and reactor systems, including solutions to improve the conversion factor to temporarily mitigate the impact of rising natural uranium prices; and
- Maintaining a technology watch for more prospective 4th generation systems such as the supercritical water reactor (SWR) and the molten salt reactor (MSR).

The current direct R&D budget for future nuclear systems is about 50 M€ with requests to increase it to 100 M€ by 2010 (exclusive of investment costs in experimental or prototype reactors of either of the above types).

Finland (FI) is primarily interested in advanced LWRs, including small nuclear power plants. Finland's Technical Research Centre (VTT) also participates in fusion technology research, including carbon-based materials that could be of interest for advanced high temperature reactors.

Germany's (D) activity related to 4th generation systems is either dedicated to safety aspects or synergies with R&D on fusion technology.

Hungary's (H) R&D for future nuclear energy systems focuses on supercritical water reactors, which contributes to attracting students to nuclear energy.

Italy (I) is actively involved in R&D on advanced nuclear systems based on LWR technologies such as AP600/1000, EPR, IRIS and Generation IV concepts in general. Specific efforts are dedicated by ENEA and ANSALDO to integral experiments to advanced technologies with liquid metal coolants (ADS transmutation systems and lead-cooled fast rectors, in collaboration with SCK in Belgium). Significant work is performed by CESI RICERCA on severe accident modelling and analysis, mainly in connection with ENEA and Euratom initiatives. ENEA is also conducting an active programme on hydrogen technologies.

Poland (P) is strongly interested in 4th generation nuclear systems, especially in high temperature reactors, in line with a research programme started in the 1960's on the conversion of coal into synthetic fuel. ADS as transmutation dedicated systems are being studied in collaboration with Sweden and the US.

Romania (Ro) is interested in hydrogen technologies.

Russia (RF) has extensive experience in the development and operation of various types of reactors. Russia together with China will join the Generation IV International Forum (GIF) in 2007. Major directions of R&D, that are mainly based on national experimental facilities include:

- Sodium fast reactors: BN-600 in operation, BN-800 under construction on the site of Beloyarsk, BN-1800 in design stages and R&D in support of the closed fuel cycle;
- Lead-cooled fast reactors: the project BREST with related R&D;
- High temperature gas cooled reactor designs: the project GT-MHR with the US;
- Light Water Reactors: VVER-1000 power plants and the project VVER-1500 at a design stage; and
- R&D for improving existing spent fuel reprocessing technologies and developing more advanced processes.

Spain (E) is interested in hydrogen, high temperature reactors and technology platforms for related technologies.

Sweden (S) is focusing current R&D on future nuclear energy systems on supercritical water reactors, which contribute to attracting students to nuclear energy. ADS are being studied as transmutation dedicated systems.

Switzerland (CH) is a member of the Generation IV International Forum (GIF). About 20% of the budget for nuclear R&D (e.g., 9 MCHF, about 6 MEuros)) is dedicated to future nuclear energy systems, especially to support development of Generation IV gas-cooled systems. Paul Schering Institute's (PSI) specific fields of expertise include very high temperature materials and mechanistic modelling of materials behaviour applicable to VHTR and GFR, as well as reactor physics (Proteus) with possible contributions to validating fast neutron core calculations and safety analyses that could be applied to GFR and other fast systems.

United Kingdom (UK) recently resigned from a position as active member of the Generation IV International Forum. NEXIA SOLUTIONS (formerly BNFL) is a partner of ESKOM in the PBMR project of high temperature gas cooled reactors. NEXIA SOLUTIONS has a general interest in fuels considered for the 4th generation systems and advanced fuel cycle processes (aqueous and pyrochemistry).

ANNEX 4 – C

Brief Survey of Contributions of the Euratom R&D Framework Programme to the R&D on Future Nuclear Energy Systems

The European R&D Framework Programme (FP) on fission reactors initially focused on safety issues, and widened to waste management and radioprotection in 2002,in the 6th Framework Programme (FP6, 2002-2006). Its budget is currently 528 M€: 319 M€ for a Joint Research Centre (JRC) and 209 M€ (share of the Commission) for contributing EU Member States. The budget for fission related R&D in the 7th Framework Programme (FP7, 2007-2011) is expected to reach 804 M€: 517 M€ for JRC and 287 M€ (share of the Commission) for contributing EU Member States. The main contribution of the JRC to future nuclear systems is via the Institute of Trans-uranium in the field of actinide-bearing fuel fabrication and characterisation, as well as fuel irradiation and post-irradiation experiments at high flux reactor (HFR).

The entry of the Euratom community as the 11th member of the Generation IV Forum on 11 May 2006, together with the orientation of both “Green Books” issued by the European Commission in 2000 and 2006 for sustainable energy development in Europe [7, 8] triggered several initiatives to implement a visible and reasonably financed R&D programme on future nuclear systems within this global budget. Previous works in this field were funded, at the margin of existing R&D programmes on safety and waste management with a budget below 20 M€/5 years (the share of the Commission).

The Michelangelo Network of European experts, that was implemented in the 5th Framework Programme (FP5, 1999-2002) strongly contributed to promoting and shaping the current part of the European R&D programme, dedicated to future nuclear energy systems, especially through the issue of a European Technology Roadmap [9]. Along the lines recommended by this network of experts, and to make it easier for European organisations to collaborate in the Generation IV Forum, R&D work on “Safety and Efficiency of Future Systems” in FP5, and “Innovative concepts to generate energy” in FP6 were given a structure of R&D projects (integrated or specific) parallel to that of Generation IV R&D projects as shown in Table 4.A3.1. A more extensive list of projects related to future nuclear energy systems within Euratom FP5 and FP6 is summarised in Tables 4.A3.2 and 4.A3.3. Additional projects within the scope of Generation IV systems in non-Euratom FP6 are indicated in Table 4.A3.4, in the fields of hydrogen production and very high temperature materials.

FP5 projects dedicated to future nuclear fission reactors amount to a total of 12.10 M€ and Euratom FP6 projects are less than 20 M€. Within this budget, a continuing R&D programme on VHTR processes and technologies is co-funded (50% by the European Commission) at a level of 2 M€/year since 1999, whereas point design studies and focused R&D work on GFR and SCWR are currently co-funded at 0.7-1.0 M€/year. The decision was taken in 2006 to support preliminary studies on the LFR at a comparable level (1.2 M€/year) and steps were taken to include activities on SFR and MSR from 2007 onwards. Initiatives in this sense are all the more urgently needed in FP7, since they are in competition with huge commitments of Europe in ITER and continuing R&D to optimise light water nuclear plant safety, waste management and radioprotection.

Current reflections on the evolution of the current R&D projects of FP6 into FP7 have led to the recommendations summarised below.

Very High Temperature Reactor (VHTR) *(Integrated project RAPHAEL)*
It is recommended that the integrated project on VHTR be funded to cover all crucial R&D for this system, which is currently not the case in FP6. Specifically, VHTR waste issues are not included. A strong coupling is also recommended with R&D areas outside the Euratom FP7 in hydrogen generation processes (R&D and technology platforms), and in high temperature materials (especially composite C/C and ceramics).

Candidate processes using the Iodine/sulphur thermo-chemical cycle, the hybrid sulphur/electrolysis cycle, and high temperature electrolysis to produce hydrogen with nuclear heat should be appropriately addressed in the non-Euratom FP7. Coupling technologies between these processes with the nuclear system (VHTR), as well as specific safety issues should be appropriately addressed in a sub-project of the VHTR integrated project.

European Laboratories have strong assets for innovative research in both fields that should be efficiently connected, being part of different areas of FP7. This connection should address R&D in a first step and possibly technology platforms *("Hydrogen production" and "Gas-cooled reactors")* in a further step.

Gas Fast Reactor (GFR) *(from the Strep GCFR in FP6 to an Integrated Project in FP7)*
It is recommended that European R&D capabilities resolve key feasibility issues of the GFR, a sustainable version of the VHTR for very high temperature applications (hydrogen) recognised as a strategic alternative system to sodium for fast neutrons. R&D on GFR key feasibility issues includes fuel and other core materials (reflector), innovative decay heat removal systems and fuel cycle processes.
A strong coupling is recommended with R&D on partitioning processes and transmutation fuels in the area of "Nuclear waste management," and on high temperature materials (especially composite C/C and ceramics) both for fusion and for non-nuclear applications (non-Euratom FP7).

Sodium Fast Reactor (SFR) *(from the SSA EISOFAR in FP6 to an Integrated Project in FP7)*
The Specific Support Action EISOFAR (roadmap for a European Initiative sodium cooled fast reactor) within FP6 aims at enabling Euratom affiliated countries to define specific strategic objectives of R&D on sodium cooled fast reactors, to appropriately shape FP7 future actions in this field.

Supercritical Water-cooled Reactor (SCWR) *(Strep HPLWR II in FP6 to be extended to FP7)*
Pursuing a technology watch on both options of this prospective reactor type (with thermal or fast neutrons) is recommended, since this technology, at least in principle, extends current LWR technology and lends itself to basic R&D work likely to trigger the interest of students in future nuclear systems (*Czech Republic, Italy, Hungary, Sweden).*

Lead Fast Reactor *(Strep ELSY launched in FP6 to be extended in FP7)*

A specific research project, ELSY is dedicated in FP6 to the preliminary design of a lead-cooled fast reactor. It should fully benefit from the results of R&D on heavy liquid metal technologies and innovative fuels performed in FP6 (in particular within the partitioning and transmutation sub-thematic area). This could be framed in international collaboration (e.g., ISTC projects supported by EC) to organise future work in FP7, and in particular, a technology watch on feasibility and performance issues of lead cooled fast reactors.

Molten Salt Reactor

The Specific Support Action, ALISIA in FP6 aims at shaping FP7 future actions on molten salt reactors and molten salt as a coolant.

Finally, the technology watch should continue on feasibility and performance issues of thorium-fueled molten salt reactors as an option to fast neutron systems for sustainable nuclear energy. And R&D on molten salts as a coolant should continue, especially in intermediate heat transfer loops coupling nuclear systems with high temperature applications (hydrogen or process heat).

Table 4.A3.1 – Correspondence between the structure of projects in FP5, FP6 and the Generation IV International Forum

European 5th Framework Programme	**European 6th Framework Programme**	**Generation IV International Forum**
• HTR-Technology Network *(Coordinated projects)*	• RAPHAEL *(Integrated project)*	• **Very High Temperature Reactor** *(VHTR)*
• Gas Cooled Fast Reactor *(GCFR) (Strep)*	• GCFR *(Strep)*	• **Gas Fast Reactor** *(GFR)*
• High Performance LWR *(HPLWR) (Strep)*	• HPLWR II *(Strep)*	• **Supercritical Water Reactor** *(SCWR)*
• Molten Salt Technology *(MOST) (Strep)*	• *ALISIA (SSA)*	• **Molten Salt Reactor** *(MSR)*
	• EISOFAR *(SSA)*	• **Sodium Fast Reactor** *(SFR)*
	• ELSY *(Strep)*	• **Lead Fast Reactor** *(LFR)*

Table 4.A3.2 – FP5 Nuclear Fission and Radiation Protection – Projects selected for funding 1999-2002 – Safety and Efficiency of Future Systems

PROJECTS	EC BUDGET (M€)	COUNTRY	ORGANISATIONS
HIGH TEMPERATURE REACTORS			
HTR-F – HTR fuel technology	1.70	D, INT, UK, F, NL	FzJ, JRC-IAM, JRC-ITU, BNFL, FANP, NRG
HTR-F1 – HTR fuel technology studies	0.80	D, INT, UK, F, NL	FzJ, JRC-IAMI, JRC-ITU, BNFL, FANP, NRG
HTR-N – HTR physics and fuel cycle studies	0.98	I, F, UK, NL, INT, NL, D	Ansaldo, CEA, FANP, NNC, NRG, JRC-UNC, KWU + Univ.
HTR-N1 – HTR nuclear physics, waste and fuel cycle studies	0.55	UK, F, NL, CH, D, I	BNFL, Cogema, CEA, NNC, NRG, PSI + Univ.
HTR-M – HTR technology - materials	1.10	F, INT, NL, D, E, D	FANP, CEA, JRC-IAM, NRG, FzJ, EA, Aubert & Duval, Turbomeca, KWU
HTR-M1– HTR technology - materials	0.70	F, INT, NL, D, E	FANP, CEA, JRC-IAMI, NRG, FzJ, EA
HTR-E – HTR components and systems	1.90	F, D, NL, E, UK, I, B,	CEA, NRG, FzJ, EA, NNC, Jeumont SA, S2M, Ansaldo, Von Karman I, Meggitt, FANP, BDE GmbH + Univ.
HTR-L – Safety approach and licensing main issues	0.49	I, E, F, UK, NL, D	Ansaldo, EA, FANP, NNC, NRG, FzJ
HTR-C – Co-ordination of HTR projects	0.20	F, D, INT, UK, B	CEA, FzJ, JRC-IE, NNC, Tractebel
OTHER REACTOR CONCEPTS AND FUEL CYCLES			
HPLWR – High performance light water reactor	0.35	F, FIN, HU, D, F, CH, JP	CEA, VTT, KFKI, FANP, EdF, PSI + Univ. of Tokyo
GCFR - Gas-cooled fast reactor	0.25	F, UK, E, NL	CEA, BNFL, EA, NRG
MOST – Review of molten salt reactor technology	0.58	B, F, I, D, CZ, S, INT,	Belgonucléaire, EdF, ENEA, FzR, FzK, UJV Rez, JRC-ITU, FzJ, Skoda + Univ.
MICANET – Michelangelo network	1.10	I, UK, F, E, FIN, D, INT, NL	Ansaldo, BNFL, CEA, Cogema, EdF, EA, ENEA, Fortum NS, FzJ, FzK, JRC-IE, NNC, NRG + Univ.
THORIUM CYCLE – In PWR & ADS	1.20	UK, F, D, INT,	BNFL, CEA, FzJ, CHRS, JRC-IAM, JRC-RMM, JRC-ITU, KWO
OTHER APPLICATIONS OF NUCLEAR ENERGY			
EURODESAL – Seawater desalination	0.20	I, E, F, P, I, CA	Ansaldo, EA, FANP, Irradiare, Candesal + Univ.
TOTAL	12.10		

Table 4.A3.3 – FP6 – Specific Programme on Nuclear Energy 2002-2006 Other Activities in the Field of Nuclear technologies and Safety Innovative Concepts to Generate Energy

PROJECTS	(M€) – EC BUDGET	COUNTRY	ORGANISATIONS
VERY HIGH TEMPERATURE REACTOR (RAPHAEL) *(Integrated Project)*			
SP CP – Coupled reactor physics and core thermo-fluid dynamics	0.5	NL, I, F, D, UK, CZ, RPC	NRG, ANS, CEA, EdF, FANP, FzJ, IKE, TUD, NNC, UNIPI, SERCO, NRI, FANP, AVR, ITU, INET
SP FT – Fuel technology	2.38	F, D, B, UK, NL	CEA, FzJ, JRC, BNFL, FANP, NRG, BN
SP BF – Back-end of the fuel cycle	1.0	D, UK, F, NL, B	FzJ, BNFL, CEA, Cogema, FANP, NNC, NRG, SCK + Univ.
SP ML – Materials development	2.04	F, E, D, NL, UK, CH, S, B	FANP, CEA, EdF, EA, FANP, FzJ, JRC, NNC, NRG, NRI, PSI, SGL, SCK, UCAR + Univ.
SP CT – Component development	0.9	F, D, NL, E, UK, I, B	FANP, CEA, IPM, NRG, FzJ, EA, NNC, JT, S2M, ANS, VKI, FANP, IEM
SP ST - Safety	0.76	B, F, I, E, D, B, UK, NL, CZ, SK	TE, FANP, ANS, CEA, EdF, EA, FANP, FzJ, JRC, NNC, NRG, NRI, VUJE
SP SI – System integration	0.58	F, NL, B, E, D, UK	FANP, CEA, TUD, NRG, TE, EA, IKE, NNC, FzJ
WP E&T – Education and training	0.84	F, D	FANP, IKE
TOTAL	9.0		
OTHER REACTOR CONCEPTS AND FUEL CYCLE *(Strep)*			
GCFR - Gas-cooled fast reactor	1.80		
HPLWR-II – Supercritical water reactor	2,50		
EISOFAR – Innovative techno. for sodium fast reactors	0.25		
ALISIA – Molten salt reactor	0.25		

MANAGEMENT OF RADIOACTIVE WASTE CONCEPTS TO PRODUCE LESS WASTE

PROJECTS	(M€) – EC BUDGET	COUNTRY	ORGANISATIONS
ELSY – European lead fast system *(Strep)*	2,95		
PUMA – Pu burning in HTRs *(Strep)*	1,85		

Table 4.A3.4 – Non Euratom FP6
Specific Programme on Hydrogen Generation 2002-2006

PROJECTS	(M€) – EC BUDGET	COUNTRY	ORGANISATIONS
HYDROGEN PRODUCTION			
INNOHYP – European roadmap of high temperature hydrogen production processes *(CA)*	0.50		
HYTECH – Hydrogen production by I/S thermo-chemical cycles *(Strep)*	1.9		
HYWAYS – Hydrogen prospective studies			

Table 4.A3.5 – Non Euratom FP6
Specific Programme on Materials 2002-2006

PROJECTS	(M€) – EC BUDGET	COUNTRY	ORGANISATIONS
MATERIALS			
EXTREMAT – Materials in extreme conditions *(Strep)*	17.4	D, A, I, UK, F, E, GR, S, SK, CZ, B, NL, P	IPP, ARCS, ARI, ATI, BIGIW, CEA, CEIT, Demokritos, DLR, EA, EADS, EMPA, EPFL-CRPP, FN, FANP, FzJ, FhG IFAM-EPW, IMSAS, INASMET, CSIC, IPP-CZ, JRC, MAN, MERL, NNC, NRG, Plansee, Polito, PSI, RAMS-CON, Siemens-CT,TUW, SGL, UKAEA, UOXF DJ, WUT + Univ.

CHAPTER 5: CONCLUSIONS

5.1 European Energy Realities

Today, nuclear accounts for nearly 30% of the total electricity supply in Europe and about 45% of the world total nuclear power generating capacity is located in Europe. In the aftermath of the Chernobyl accident in 1986, a number of European countries have committed to phasing-out their nuclear capacities, and most of them have no alternative fallback solution. All future scenarios suggest that energy demand is set to grow strongly all over the world and, in particular in the large emerging economies in Asia. Increasing competition for energy resources, above all for oil and gas, and rising energy prices are expected to change the global energy scene and Europe's role in it.

How will these changes affect the European energy sector? Is the political process on track? Europe (excluding Russia) currently imports 50% of its energy, and this figure is expected to grow to approximately 70% by 2030. How is Europe preparing for this? More effort should go towards harmonisation of energy policies across Europe, and support for an open dialogue with energy producing and transit countries. The European energy sector currently faces three major challenges :

- Ensuring security of energy supply;
- Stabilising and even reducing greenhouse gases (GHG) emissions; and
- Maintaining economic competitiveness by keeping energy prices at an affordable level.

To address these challenges, the European Commission published a Green Paper ("A European strategy for sustainable, competitive and secure energy") which outlines ambitious goals for future development of the European energy sector. It suggests that a sustainable energy future can be achieved by improving energy efficiency and increasing the use of energy technologies with low GHG emissions.

In terms of its future energy choices, Europe is presently at a crossroads: more than 80% of installed capacity (currently more than 1,000 GW) will be over 30 years old by 2020. This means a large number of power plants will retire over the 2010 – 2030 period; it is a major challenge but also a unique opportunity, since the choices made today will be shaping Europe's energy future for decades to come.

This situation is not unique to Europe, and many countries in other parts of the world are facing similar issues. All energy resources, including nuclear, will be required to address the challenges of climate change, security of supply and high volatility of fossil fuel prices.

5.2 Main Issues

All energy technologies have their advantages and drawbacks, and in the European context, in particular, given Europe's high dependency on energy imports, nuclear energy should be considered as an integral part of a feasible and already available solution to address climate change and security of supply. For instance, in the "EU- 25" group, extending the operation of the existing nuclear plants beyond their initial defined service life, when it makes economic sense, could avoid 700 million tonnes of CO_2 per year, i.e. around 15-20% of the total annual emissions in the EU. This would also minimise the risk of shortages in fuel supply, since uranium world resources are sufficient enough to power three times the number of existing nuclear power plants for more than a century, with current technologies and at current prices.

Given nuclear's excellent operational safety record in Europe, during the past five decades, public concern in many countries today is shifting from operational risks to nuclear waste management. The only significant nuclear event, the Chernobyl accident, occurred due to specific design flaws of one particular type of reactor and inadequate operational practices, which together led to a nuclear slowdown in Europe for 20 years. Since then, the European operators together with the nuclear safety authorities have improved the safety standards even further and today, all European plants demonstrate excellent safety performance.

Technologies for safe management of low and intermediate level nuclear waste are well-known and widely available. In terms of high-level wastes, while some countries have already made significant progress in the political process to select sites for final repository, others have just begun the process. There is no single technical solution suitable for every country, as the operating environment is different for every single power plant.

Decommissioning of old plants is already included in the full operational cost cycle and it has a certain impact on waste management, depending on the size and the number of reactors. The average cost of decommissioning is around 300 Euros/kWe, except for gas-cooled reactors. Almost all nuclear operators in Europe have allocated sufficient funds to cover future decommissioning costs, and the remaining few have agreements with local authorities, which have committed to undertake this task. The discounted decommissioning costs for new plants, which will be due for retirement in 60 years or more is between 0.5 – 1.0 Euro/MWh.

In addition to nuclear waste management and decommissioning, the public is also concerned with nuclear proliferation and the risk of terrorism, although the emphasis given to these issues varies between the countries. Facts-based information campaigns, transparency of the institutions and an open public debate on nuclear matters are the tools to improving public awareness and understanding of energy issues and have led to public support for nuclear energy in countries like Finland, Sweden and France.

Like any energy technology, nuclear will have no future if it cannot compete in the market. In many European countries, nuclear is competitive without special support. For the main part of the existing European fleet, the production cost is below 20 Euros/MWh considering that almost all the plants have been fully depreciated. Such a good economic performance is encouraging life-extension and capacity increases of the majority of existing plants.

5.3 Outlook

Advanced nuclear technologies (Generation 3) are already available on the market for deployment in new power plants. Examples of these are under construction in Finland, France, Japan, Romania and Taiwan. The overnight cost (investment cost excluding interest during construction) of large size reactors units on today's market is in the range of 1300-1800 Euros/kW depending on the unit size, number of units per plant and economies of serial production. The final investment cost, however also depends on local legislation, taxes and discount rate. With a stable political situation, clear regulatory framework (site location, decommissioning etc.) and utilities with experience in the nuclear field and possible manufacturing series effects, the total generation cost can be around 40 Euros/MWh. In certain specific conditions, they can be considerably lower (around 30 euros/MWh) or higher (around 55 euros/ MWh). These costs include future outlays such as decommissioning and waste disposal (possible uncertainties about these cost components will only slightly affect the total generation cost (by around 2 Euros / MWh). Even without inclusion of the CO_2 penalties in the costs of fossil fuels, nuclear energy appears as an economically attractive option.

Today, nuclear is an integral part of the European energy scene. Tomorrow, success will be defined by the following key conditions:

- Stability, consistency and predictability of market rules to ensure investor friendly environment:
- Independence and transparency of safety regulations;
- Agreement on a common technically feasible, economically efficient and publicly acceptable framework for waste disposal;
- Simple and rapid process for granting construction and operational licences;
- Standardisation and scale effects for reactor manufacturers;
- Support for nuclear R&D, in particular for Generation 4 technologies, which are expected to become available on the market around 2030-2040 and will bring about a dramatic increase of uranium utilisation by nearly 80 times; to secure sustainable generation of electricity in a possible context of rising uranium prices and also to co-generate by-products such as hydrogen, synthetic hydrocarbon fuels and high temperature process heat for other industrial applications;
- Active involvement of all stakeholders in the consultation and implementation processes; and
- Equitable distribution of risks and rewards between all involved.

European countries, and the EU Member States in particular, must seriously consider including the nuclear option in their energy policies. This also includes improving public awareness about the energy issues, providing factual information and conducting comprehensive and efficient communication campaigns. The European members of the World Energy Council (WEC) are ready and willing to work together with all stakeholders to ensure a facts-based, balanced and unbiased approach to the assessment of the nuclear option, as a part of WEC's strategy of keeping all energy options open.

APPENDIX A

List of Abbreviations/Acronyms

ABWR	Advanced boiling water reactor
ACR	Advanced Candu reactor
AECL	Atomic Energy of Canada, Limited
ALARA	As low as reasonably achievable
B€	Billion Euros
BWR	Boiling water reactor
CANDU	Canadian deuterium uranium system
CEA	Commissariat à l'Energie Atomique (France)
CBI	Confederation of British Industries
CCGT	Combined cycle gas turbine
CO_2	Carbon dioxide
COL	Combined construction and operating licence
CORWM	Committee on Radioactive Waste Management
CSR	Corporate social responsibility
D&D	Decommissioning and dismantling
DC	Design certification
DiP	Decision in principle
DOE	Department of Energy (US)
DR	Discount Rate
EAF	Energy availability factor
EAR	Estimated additional reserves
EIA	Environmental Impact Assessment
EISOFAR`	European Initiative Sodium Cooled Fast Reactor
EPR	European pressurised water reactor
ESP	Early Site Permit
EU	European Union
EUR	European Utility Requirements
FERC	Federal Energy Regulatory Commission (US)
FOAK	First of a kind
GCR	Gas cooled reactor
GE	General Electric
GFR	Gas-cooled fast reactor
GHG	Greenhouse gases
GIF	Generation IV International Forum
GNEP	Global Nuclear Energy Partnership
GPR	Groupe Permanent Réacteur" (French Advisory Group to the Safety Authorities)
GRS	Gesellschaft fur Reaktorsicherheit (Germany's Central Institution for Nuclear Safety)
GT-MHR	Gas turbine modular high temperature reactor
Gtoe	Gigatonnes of oil equivalent
GW	Gigawatt
GWe	Gigawatt electric
HEU	Highly Enriched Uranium

HFR	High flux reactor, Petten (Netherlands) (JRC/EC)
HLW	High level waste
HSE	Health and safety executive
HTGR	High temperature gas cooled reactor
HTR	High temperature reactor
IAEA	International Atomic Energy Agency (UN)
IDC	Interest during construction
IEA	International Energy Agency (OECD)
IGCC	Integrated gasification combined cycle
INB	Basic nuclear installation
INES	International Nuclear Event Scale
INPRO	International Project on Innovative Nuclear Reactors
IPHE	International Partnership for Hydrogen Economy
IPP	Independent power producers
IRR	Internal rate of return
IRSN	French Institute for Radiological Protection and Nuclear Safety
ITER	International thermonuclear experimental reactor
JRC	Joint Research Centre (EU)
kg	kilogram
kWe	kilowatt electric
kWh	kilowatt hour
LCOE	Lifecycle cost of electricity
LFR	Lead-cooled fast reactor
LRMC	Long run marginal cost
LWR	Light water reactor
M€	Million Euros
MSR	Molten salt reactor
MSWU	Million separative work units
Mt	Million tonnes
MW	Megawatt
MWd/t	Minimum days per metric tonne
NatU	Natural uranium
NEA	Nuclear Energy Agency (OECD)
NEI	Nuclear Energy Institute
NGO	Nongovernmental organisation
NOx	Nitrous oxide
NPP	Nuclear power plant
NPV	Net present value
NRC	Nuclear Regulatory Commission (US)
NSSS	Nuclear steam supply system
NU	Natural uranium
NWF	Nuclear Waste Fund
O&M	Operation and Maintenance
OECD	Organisation for Economic Cooperation and Development
OVN	Overnight
P	Price
PBMR	Pebble bed modular reactor
PHWR	Pressurised heavy water reactor
PSI	Paul Schering Institute, Switzerland
PSR	Preliminary safety report

PV	Photovoltaic
PWR	Pressurised water reactor
R	Interest rate
R&D	Research and Development
RAR	Reasonably assured resources
ROE	Return on equity
ROIC	Return on invested capital
SCWR	Super critical water-cooled reactor
SFR	Sodium-cooled fast reactor
SO_2	Sulphur dioxide
SRMC	Short run marginal cost
STUK	Centre for Radiation and Nuclear Safety (Fin.)
SWU	Separative work unit
t	tonne
TWh	Terawatt hours
UK	United Kingdom
URD	US user requirements document
US	United States
USD	US dollars
US$/lb	US Dollars per pound
USNRC	US Nuclear Regulatory Commission
VHTR	Very high temperature reactor
VTT	Finland’s Technical Research Centre
VVER	Light water reactor (Russian)
WANO	World Association of Nuclear Operators
WACC	Weighted average cost of capital
WEC	World Energy Council
WERNA	Western Europe Nuclear Regulators Association
WNA	World Nuclear Association
WPNS	Working Party on Nuclear Safety